UNIVERSITY of TASMANIA

THE USE OF WEARABLE AMBIENT DISPLAYS TO ENHANCE AWARENESS OF PHYSICAL ACTIVITY

by

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Signed: ______________________________
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Date: 30 October 2016

The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University.

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ABSTRACT

There has been extensive research into using computers to help people to monitor their physical activity. Most existing self-monitoring approaches employ high-complexity, high-engagement interfaces with a focus on numbers, text and graphics. An alternative are low-complexity interfaces—those that employ simple metaphors to convey information—such as ambient displays. Research has shown that these interfaces could be equally effective in assisting users to monitor and subsequently change their behaviour. Engagement with existing smartphone-based or fixed ambient displays presupposes that the user is also engaged in some other unrelated activity (looking at a phone or walking past a screen), limiting their usefulness. Wearable ambient displays that are persistently visible to the user could overcome this problem, and have the additional benefit that they help to engage the wearer with others in discussions around the information displayed.

Using a design process facilitated by accessible rapid prototyping tools such as 3D printing, I developed a wearable device that could track the user's level of physical activity and, implementing a novel ambient display design, provide the user with information about their own activity levels and those of others. I evaluated the final device in a user study with 40 participants over six weeks. The results, both qualitative and quantitative, indicated that participants were able to engage with the ambient visualisation and it motivated them to think about and discuss physical activity. Further research is needed to establish the potential for long-term behaviour change.

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In perpetuum ave atque vale.

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Introduction

1.1 Ubiquitous Computing

Computers have profoundly changed the way we collect, store, retrieve and interact with information. “Big data” systems continuously monitor people, their environments and behaviours, storing and processing vast amounts of data. Intelligent systems harness these data to create information that allows computers to better understand us, and to help us better understand ourselves and the world in which we live. Personal computers, smartphones, tablets, and the Internet give us access to this information anywhere, at any time, almost instantaneously.

Traditionally, interacting with information in a computer system required the user to enter the computer’s environment. The user would sit in front of a computer terminal, enter commands and queries on a keyboard, and view output on a printer or screen. The user needed to know and understand the language of the computer in order to know which commands to enter and to interpret the computer’s output. With the home computer revolution in the 1980’s computers became easier to use, although the focus on “computer literacy” still spoke of devices with non-intuitive interfaces that required a special effort on behalf of users to learn.

Mark Weiser, in his seminal article "Computer for the 21st Century" (1991), proposed a radical new style of interaction now known as "Ubiquitous Computing". He foresaw an era beyond personal computing, with the "person and machine staring uneasily at each other across the desktop", where computers and information would instead be embedded seamlessly into the user's natural environment. Computers would be integrated into objects with form factors that paralleled familiar real-world objects (tabs, pads and boards) and users would interact with them in a more natural way, such as with speech and gestures.

Weiser and Brown (1996) proposed a form of ubiquitous computing called "calm technology", in which users would monitor information using displays embedded in their natural environment. Placing information in the user's periphery, they argued, is non-intrusive and therefore naturally encalming. When the user notices something that requires their attention they could "re-center" on the information presented and take action. These peripheral displays are now more commonly referred to as "ambient displays" (Section 2.4).

They discussed the example of the "dangling string", a string attached to the ceiling that would whirl in response to network traffic within a building, with greater motion representing a larger volume of traffic. The string in this case allows a network administrator to monitor network traffic levels in their periphery (ambiently). If the administrator notices the string moving quickly they could then decide to engage with a centre-of-attention display such as a network traffic monitoring program running on a PC (re-centring).

Many of Weiser's ideas have been realised over the past ten years. Smartphones, tablets, and interactive whiteboards have the form factors of tabs, pads and boards. Voice assistants, such as Siri, are now commonplace. Recommender algorithms suggest books we might like to read or television shows we might watch. Intelligent vehicle satellite navigation systems analyse trip data in real-time from millions of journeys to help us find faster routes and avoid accidents. Vibrating alerts on phones are a form of ambient information transfer.

The present age of ubiquitous computing has seen computers increasingly play a more intimate role in our lives—a role which continues to expand into areas such as personal health and wellbeing.

1.2 Applications to Health

A significant and growing area of research is using computers to help people interact with health-related information in connection with exercise, nutrition, smoking and drinking. The hope is that, through engaging people with this information, they might be better able to make healthier choices and to change negative behaviours.

The potential benefits of encouraging people to be more active are clear—in Australia 35% of adults are overweight and a further 28% are obese (Australian Bureau of Statistics, 2013). Treatment of obesity-related chronic disease costs the Australian public health system $10.7bn each year (Colagiuri et al., 2010). If people were helped to better manage their own health the impact on them, their families, and the health system could be significantly reduced.

Broadly, there are many existing computer-based interventions. I define a taxonomy consisting of three main categories, each covering a different way users engage with activity information through an intervention. *Informational* approaches use computers to provide users with information about healthy behaviours (such as exercise plans or healthy eating ideas) in the hope that reading and thinking about that information will motivate change. *Self-monitoring* approaches help the user to record and analyse their own behaviour (often with the use of electronic sensors) with the intention that the act of monitoring will itself act as a motivator for change. *Direct* approaches, such as physically active computer games, engage the user directly with healthy behaviour. The information provided, such as a score, or progress toward achievements, relates to this direct engagement.

The effectiveness of all of these approaches is premised on successfully engaging the user with the intervention itself. This engagement in turn is premised on the complexity and engagement requirements of the computer interface employed. Users must be motivated to visit the website, wear the exercise tracking device, play the active game or whatever else the intervention requires. If the interface is too complex, users may be unable to understand it. If it requires too great an investment of time, users may be unwilling to use it long enough for it to be effective.

There are a number of examples in the literature of where "calm technology" approaches, such as ambient displays, have been used effectively as low-complexity, low-engagement interfaces to physical activity information. Consolvo et al. (2008) developed a mobile phone app that represented the users' physical activity graphically as a flower garden—more flowers represented increased physical activity. Lin et al. (2006) developed a virtual fishbowl display that represented users as fish that grew larger and gained spots as the user became more active. Similar to how the "dangling string" metaphor answers the question "how busy is the network?", these metaphors answer the question "how busy have I been?"

In addition to using an ambient display to show users' own physical activity levels, Lin et al. (2006) showed that ambient displays could also provide an element of social awareness and persuasion. In a multi-user version of their "Fish'n'Steps" display a single fishbowl contained multiple fish, each representing an individual in a group of work colleagues. If the group as a whole were sufficiently active decorations would be added to the bowl. If the group weren't active enough the decorations would be removed and the water would become murky. Consolvo, McDonald, and Landay (2009) term this *social persuasion*—I would categorise it as *implicit* persuasion as it is social persuasion, but by indirect means.

1.3 Wearable Ambient Displays

Existing ambient activity displays, implemented using mobile phones or fixed display screens, have two important limitations: they are not persistently visible to the user, and they may not be able to prompt the user to re-centre when they are primed to take action. For example, people who use their smartphones for sedentary activities, such as mobile gaming or social media, may see the ambient display at times when they are unwilling to exercise. Fixed displays at a workplace will be viewed by employees during weekdays when they may not have the time to exercise, rather than on the weekend when they may be able to.

Wearable ambient displays do not suffer from the same limitations. Being worn externally on the user's body they are persistently visible and therefore more likely to be noticed at times the user is primed to engage in physical activity. For example, upon leaving the office for the day the user might happen to glance at the display, notice that it is indicating a low level of physical activity, and subsequently walk part way home rather than taking the bus (re-centring).

Lim et al. (2011) proposed an additional benefit of wearable ambient displays—their highly-visible nature encourages others to engage with the user in discussion about the information presented on the display. These discussions could increase the user's awareness of their activity levels and prompt them to think more about them. I term this *explicit* social persuasion, as the persuasion is through direct interaction with others.

Most research into wearable ambient activity displays is relatively recent. This is due mainly to the design and engineering challenges of creating a device that can monitor the wearer's activity and present a persistently visible display, in a form factor that is small and comfortable and that, ideally, is connected wirelessly to the Internet. This has only become practical within the last ten years, and accessible prototyping technologies have only been available within the past five.

1.4 My Research

I proposed a number of unanswered questions about wearable ambient displays.

Information Presentation—How do we present information in a way that:

- Users can comprehend it?
- Conveys an accurate picture of a user's physical activity and that of others?
- Enables explicit social persuasion while respecting the user's privacy?

Design—How should we design wearable ambient display devices such that:

- Users accept and are satisfied with the devices?
- Users find the devices easy to use?

Motivation—Could these displays:

- Engage users to think about or discuss physical activity?
- Motivate users to be more active?
- Create long-term exercise behaviour change?

These questions fall into three categories—Information Presentation, Design and Motivation. The Information Presentation questions are concerned with whether information is provided in a way in which users can comprehend it. These questions also consider the balance between creating an eye-catching display and respecting users' privacy. The Design questions are concerned with the aspects of the design of wearable ambient displays that affect their usability. Specifically, which design aspects affect ease-of-use and perceived satisfaction. Motivation questions are concerned with whether users are motivated to think about and discuss physical activity, to become more active and to change their behaviour in the long-term.

The selection of the Information Presentation research questions was informed by the work of Consolvo et al. (2006), and Mankoff et al. (2003). Consolvo et al. presented a set of *Design Requirements for Technologies that Encourage Physical Activity*. These included giving users proper credit for their activities, providing personal awareness of physical activity, supporting social influence and considering the physical constraints of users' lifestyles. Mankoff et al., in *Heuristic Evaluation of Ambient Displays*, presented a set of heuristics specifically applicable to the design and evaluation of ambient displays. These included providing just enough information, that is useful and relevant, with a consistent and intuitive mapping, in a way that is unobtrusive and easy to monitor (peripheral). They also recommended displays have an aesthetic and pleasing design that matches the user's environment.

If designers ought to present useful and relevant information using an intuitive mapping, how is this best done using a wearable ambient display? If a display should be unobtrusive and fit into a user's lifestyle and environment, how can this be achieved using an overt display, in a way that respects users' privacy and the social norms of their environment? How do we present physical activity information, with such a display, in a way that users gain an awareness of their activity and feel adequately rewarded for it?

The choice of Design research questions was driven by the principles of usability, specifically those that an interface should be easy to learn and subjectively pleasing (Nielsen, 1994). In answering the above questions, can we design a wearable ambient display that is both easy and satisfying to engage with? These questions engage with the practical issues that come with designing a wearable user interface, such as comfort, aesthetics, charging and battery life, and Internet connectivity. They also connect with broader attributes of system acceptability, such as social acceptability, cost, reliability and compatibility.

The Motivation research questions address the ultimate goal of exercise ambient displays—to engage users with information about their physical activity, and in doing so, to motivate them to become more active. Acknowledging that behaviour change is a complex, long-term process, Klasnja, Consolvo, and Pratt (2011) suggest focusing on the putative active elements of physical activity interventions, such as the way in which they convey information, rather than direct outcome measures such as minutes exercised or calories burned. I have therefore weighted my research toward showing that users engage with the information presented on a wearable ambient display, rather than proving any actual increase in physical activity. I nonetheless consider the question of how to create long-term behaviour change, and I discuss ways in which this might be achieved and measured with this type of technology.

To answer these questions I decided to employ a design research approach. I designed and prototyped a wearable ambient display device and two activity display metaphors. The first display showed the user's individual physical activity level as a colour on a spectrum from red to green. Red represented a level of activity over the last week below the user's long-term average activity, yellow represented an average level of activity and green represented reaching an activity goal above the average. (Figure 1.1)

The second display showed the user's activity in the context of a group of other users. Each user in the group was represented as a distinct colour in a row of coloured lights that would change position to represent a ranking of users against each other based on physical activity. Lights appearing above the user's individual activity light represented other users who were more active, whilst lights below the user's individual activity light represented others who were less active. (Figure 1.1)

I evaluated the wearable ambient display device, and individual and group activity displays, in a user study with 40 participants who wore the device over six weeks. Some participants received only the individual display, others received the group display and some received both. I evaluated variations of both the individual and group display, with users receiving a device that provided them with easy or difficult

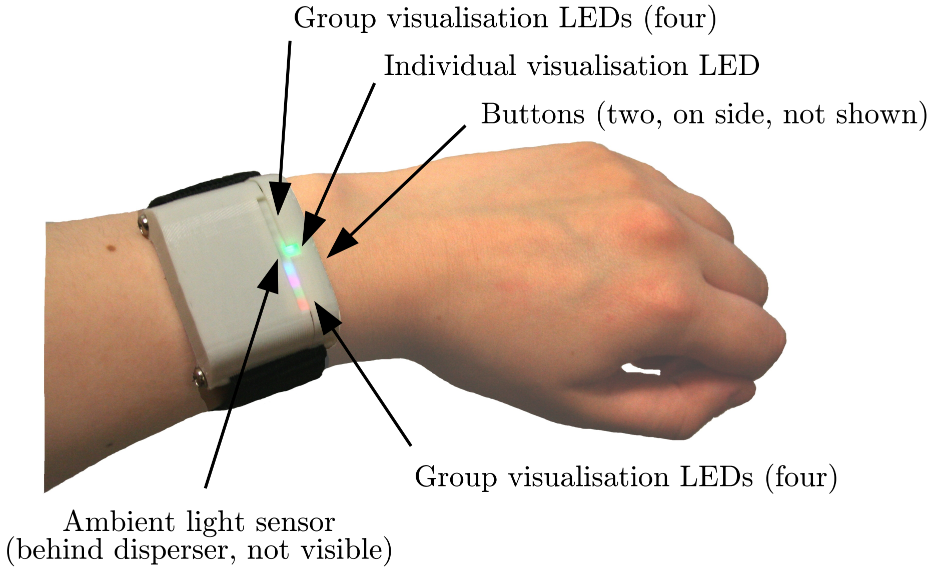


Figure 1.1: The Activthings device

goals, that tolerated different degrees of recidivism, or displayed a ranking calculated over a long or short time period.

I showed that users were able to comprehend both the individual and group activity displays. Users who received the individual display reported monitoring it and responding to the colour shown. Users did not report monitoring or reacting to the group display in the same way, due to low concurrent wear and users leaving the study. At least some users, however, reported being motivated by the group display, suggesting a different evaluation methodology could yield better results.

Overall, the design of the display device was effective. The highly visible nature of the wearable display device was a positive aspect, engaging users in discussions with others about physical activity. The use of a 3D-printed housing yielded a device that was attractive and that was a comfortable shape for continual wear. Users were still concerned about the size and appearance of the device, however the device was nonetheless able to gain user acceptance over six weeks.

The putative active elements of the device were the display of activity information, and the engagement of users with that information (Klasnja et al., 2011). I showed that these active elements were functioning correctly, and I was able to gain insight into aspects of the design of the wearable device and displays that affected comprehension and engagement. A future study would attempt to measure actual behaviour change over a longer period of time.

Through this research I make three main contributions.

- I present the design and evaluation of novel exercise ambient displays and the wearable devices, algorithms and software systems that support them.
- I show that wearable ambient displays support both implicit and explicit social persuasion, and that their highly visible nature is a source of motivation for users.
- I show that rapid prototyping technologies, such as 3D printing, are effective for creating high-fidelity prototypes of novel wearable technologies that can successfully gain user acceptance in short-duration user studies.

I conclude that wearable ambient displays are an effective approach to engaging users with information about their physical activity. Their highly-visible nature, far from being a negative aspect, mean they have the unique ability to engage wearers in conversations with others about behaviour change.

1.5 Outline and Publications

In Chapter 2, I outline a number of different computer-based interventions than aim to motivate users to become more physically active, both commercially produced and in the research space. I argue that these different interventions should be classified, according to a taxonomy based on the properties of motivation and persuasion, as “informational”, “self-monitoring” or “direct”. Further, that use of these interventions depends on their level of complexity and engagement requirements. I show that, for low-complexity, low-engagement ambient displays, the utility of existing interfaces is limited by the presence of inherent engagement pre-requisites. I motivate for the use of wearable ambient displays to address this issue, and argue that they have the particular advantage of enabling explicit social persuasion. I show that there is a gap in the design space, as advances in technology have only recently made these types of displays feasible to construct and practical to use.

In Chapter 3, I present a series of research questions relating to wearable ambient displays and their potential to prompt behaviour change. I argue for a design-based research methodology, where I would design, prototype and evaluate my own wearable ambient display devices. I present a series of evaluation criteria and discuss the evaluation methods and instruments I would use to address each of them.

In Chapter 4, I discuss the design, construction and evaluation of the "Activmon" wearable ambient display device. I detail a "traffic light" metaphor for presenting individual activity information on an ambient display. I also detail algorithms to create a representation of the physical activity of a group of users, and to present this representation on individual users' displays. I discuss the results of a small-scale user study.

I then discuss the design, construction and evaluation of the "Activthings" wearable ambient display device. I detail a new "continuum" approach, which aims to represent individual physical activity using an ambient display in a manner that better reflects the variability of real-world physical activity. I detail a rank-based approach to creating and visualising fair comparisons between users in a group using ambient displays.

In Chapter 5, I present the results of a user study, where 40 participants wore the "Activthings" display over a six week period in their day-to-day lives. I discuss how these findings address the research questions I posed in the categories of Information Presentation, Design and Motivation.

In Chapter 6, I present a short summary of my approach and the key findings. I outline what I believe are the main contributions of this research. I discuss the limitations of my methodology and results, and future research possibilities.

A number of published, peer-reviewed papers arose from this research.

In *ActivMON: A Wearable Ambient Activity Display* (Burns, Lueg, & Berkovsky, 2011), I argued for a wearable activity monitor that was wrist-mounted, unobtrusive, and that had wireless data transmission. I introduced the individual and group activity displays employed by the Activmon device, and the algorithms used to create those displays (described in Chapter 4). I presented the results of an initial validation (provided in Appendix Section B.1).

In *Empower Everybody: Designing Persuasive Wearable Technology for User Empowerment* (Burns, Lueg, & Berkovsky, 2012b), I distinguished between direct approaches to motivating users to be physically active—those that employed explicit persuasion—and self-monitoring approaches—those that employed subtle persuasion. Further, I distinguished between high-complexity, high-engagement displays and low-complexity, low-engagement displays. I argued that ambient displays are an example of the latter, and that wearable ambient displays, in particular, overcome some of the limitations of screen-based displays (discussed in Chapter 2). I highlighted the intimate connection between wearable technologies and users' bodies, and discussed the "jail bracelet" effect observed in the Activmon user study (Chapter 4).

In *Using Personal Informatics to Motivate Physical Activity: Could we be doing it wrong?* (Burns, Lueg, & Berkovsky, 2012c), I again presented the distinction between high-engagement, high-complexity and low-engagement, low-complexity displays. I suggested that users with a low motivation to undertake physical activity would also have a low motivation to employ high-complexity, high-engagement interfaces (Chapter 2). I discussed the results of the Activmon study relating to usability, where I found that device size and form, accuracy of activity recognition and battery life were important issues for users (Chapter 4).

In *Activmon: Encouraging Physical Activity Through Ambient Social Awareness* (Burns, Lueg, & Berkovsky, 2012a), I discussed the results of the Activmon study in detail, showing users' activity levels during the study period, group indications delivered and frequency with which devices were worn. I presented quotes from the semi-structured interviews I conducted after the study, and discussed the most prominent themes (Chapter 4).

This paper was accepted into *The Conference on Human Factors In Computing Systems* (CHI), the pre-eminent Human-Computer Interaction (HCI) conference, and published in a volume of extended abstracts in which other influential papers in the field have previously featured.

In *Colours That Move You: Persuasive Ambient Activity Displays* (Burns, Lueg, & Berkovsky, 2013), I acknowledged a key limitation of the Activmon individual display—that day-to-day physical activity was too volatile a measure to present to users directly. I provided the design for a continuum display, and associated algorithm, that represented changes in physical activity over a longer period of time, encouraging users to focus on longer-term trends rather than short-term fluctuations (Chapter 4). I discussed the way in which the goal- and red-line settings for that algorithm would affect the degree of recidivism accepted by the system, and the perceived difficulty reaching goals (Chapter 5).

Chapter 2

Literature Review

In the previous chapter I wrote of the potential benefit of computer-based interventions to motivate users to become more physically active. I proposed a taxonomy which focuses on the way in which information is presented to users as part of an intervention.

Informational approaches provide users with information in an attempt to educate them about the benefits of physical activity. *Self-monitoring* approaches engage users in the act of collecting and monitoring their own physical activity information. *Direct* approaches engage users directly with physical activity—engaging with the intervention requires the user to be active—and provide them with information relating to this engagement.

These types of approaches vary most in two features critical to behaviour change: *persuasion* and *motivation*. Persuasion refers to the degree to which an intervention prompts users to become more active. It can be subtle, where users are gently encouraged to be more active, or explicit, where users are directly instructed to be active. Motivation refers to the way in which persuasion is translated into action. It can be internal, where users motivate themselves to change, or external, where the intervention is the primary motivator. (Figure 2.1)

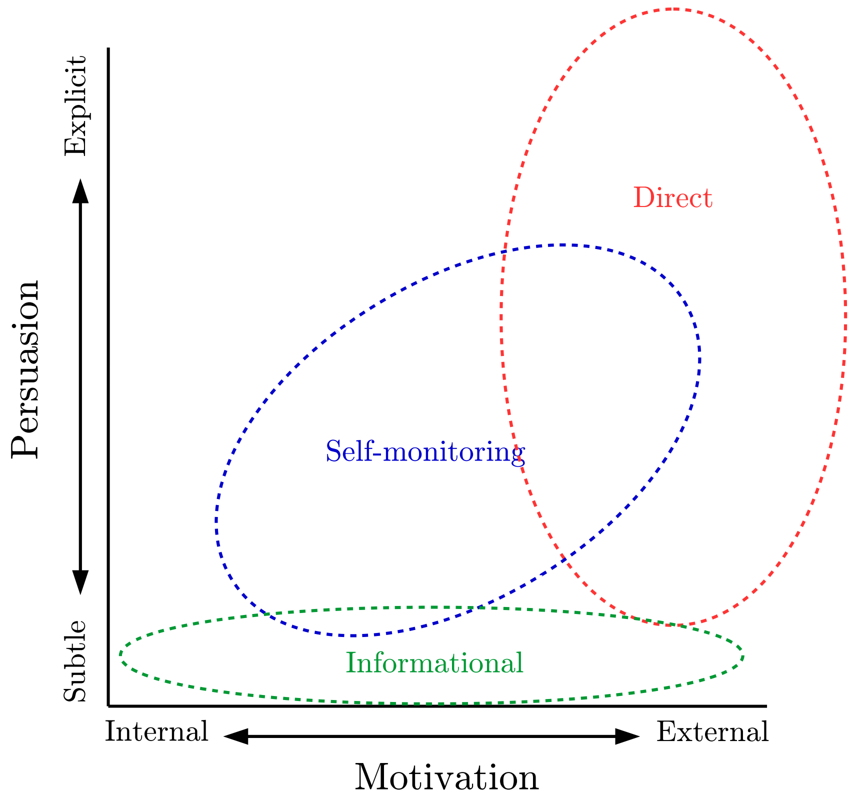


Figure 2.1: Three main approaches arranged by motivation and persuasion

I categorise *Informational* approaches as employing subtle persuasion, while relying on both internal and external motivation. The provision of information about healthy activity is subtly persuasive and may appeal to users' internal motivation, although the intervention itself may motivate users externally. Similarly, *Self-monitoring* approaches use the act of monitoring oneself as a form of subtle persuasion (although less subtle than simply providing information), and cover the spectrum of internal and external motivation. The motivation provided by *Direct* approaches is external, as the intervention itself provides an activity to engage in. The level of persuasion employed to engage users with the intervention can range between subtle and explicit.

This taxonomy is an attempt to fit existing approaches into a structured model, rather than a statement that a particular intervention must or must not employ a particular type of persuasion or motivation. Therefore, not all approaches will fit

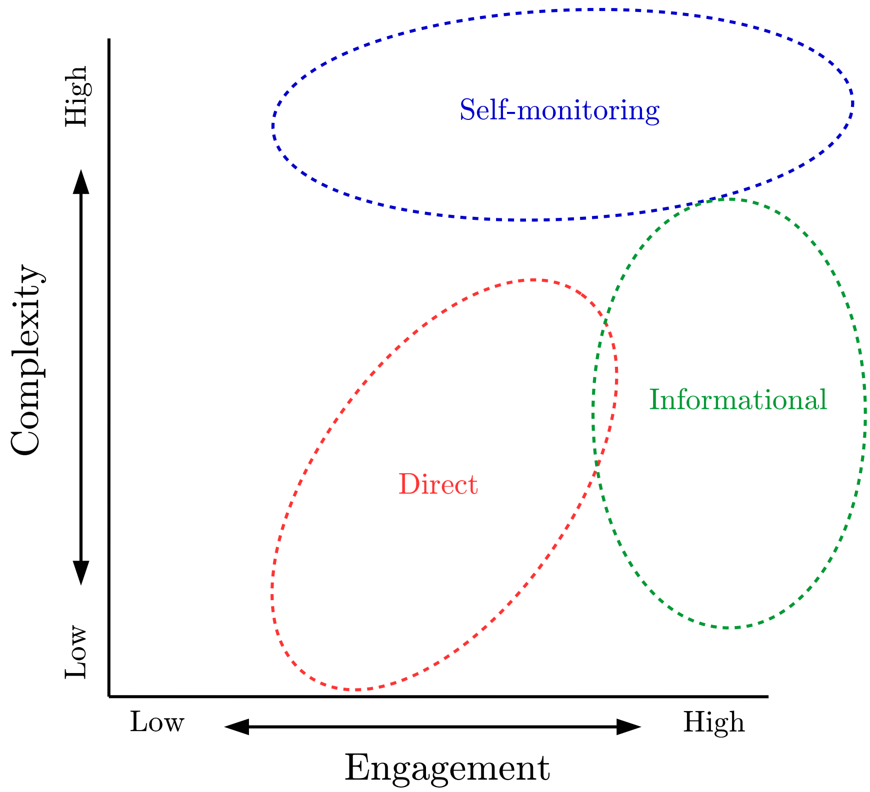


Figure 2.2: Three main approaches arranged by complexity and engagement

rigidly into this model.

For any of these approaches to be effective, users must first engage with the interfaces provided. This engagement is premised on users' ability and motivation to interact with the interface. Users' ability to interact with an interface relates to its complexity—an interface that is very complex may be difficult to comprehend. Users' motivation to interact with an interface relates to the level of engagement demanded—an interface which demands a high level of engagement (in terms of frequency and/or time commitment) may act as a barrier to some users.

When existing approaches are categorised into the complexity and engagement classification spaces (Figure 2.2), it becomes apparent that there is scope for further work to be done in the area of low-engagement, low-complexity technologies. Ambient displays are a promising example of such a technology.

This literature review focuses specifically on the presentation of health information, from a Human-Computer Interaction (HCI) perspective. Whilst research pertaining to health and the psychology of behaviour change is mentioned briefly, it is not the focus of the work presented in this thesis.

2.1 Informational Approaches

Informational approaches aim to inform users about physical activity and its health benefits. The intention is that users will internalise the information, thinking about how it applies to their personal situation, and then plan and enact behaviour change. Examples are websites which provide information about physical activity and its benefits, and social networks that allow users to exchange exercise related information.

Informational approaches employ subtle persuasion, in that it is up to the user to comprehend the information provided and decide what action to take. Motivation is mainly internal, where users enact and monitor behaviour change on their own, but it could also be external in situations where a human or virtual coach is provided to monitor users' progress. (Figure 2.1)

These approaches require a high level of engagement from users, as they must read and comprehend the information presented, consider how the information is applicable to their own behaviour, then plan and carry out resulting actions. The need to read and comprehend possibly complex health information means these approaches are of medium complexity. Informational approaches that employ coaching have somewhat lower complexity as the coach can perform some of the reflection and interpretation tasks that would normally be the responsibility of the user.

2.1.1 From Print to the Web

In the past, physical activity information was delivered in printed form such as pamphlets and books. In-person follow-up could be used to monitor users' progress. With the advent of personal computers and home Internet access, there is now the opportunity to deliver information in a more convenient and interactive form and even to tailor information to individuals. Follow-up can be conducted more efficiently and conveniently using email and videoconferencing.

Leslie, Marshall, Owen, and Bauman (2005), McKay, King, Eakin, Seeley, and Glasgow (2001), M. Van den Berg et al. (2006), Rydell et al. (2005), Spittaels, De Bourdeaudhuij, and Vandelanotte (2007), Hurling et al. (2007) have explored the use of websites to provide physical activity and nutrition information (Figure 2.3). In each of these studies, information delivered through websites was targeted to individual participants using one or more psychological models (such as the transtheoretical model (Prochaska & Velicer, 1997)) or by having a human coach or expert create a specific program for each person. Participants were contacted by email or mobile phone text message. Outcomes were measured using some combination of website usage statistics, participant self-report, and wearable electronic activity monitors.

Meta-reviews of these approaches have found weak or mixed evidence for their effectiveness, although comparisons are frustrated by the lack of a standardised methodology or outcome measures (M. H. Van den Berg, Schoones, & Vlieland, 2007) (Kroeze, Werkman, & Brug, 2006). Studies comparing print and online channels for delivering health interventions have found computer-based interventions to be no better, or even worse, than those using traditional print media (Marshall, Leslie, Bauman, Marcus, & Owen, 2003) (Marks et al., 2006).

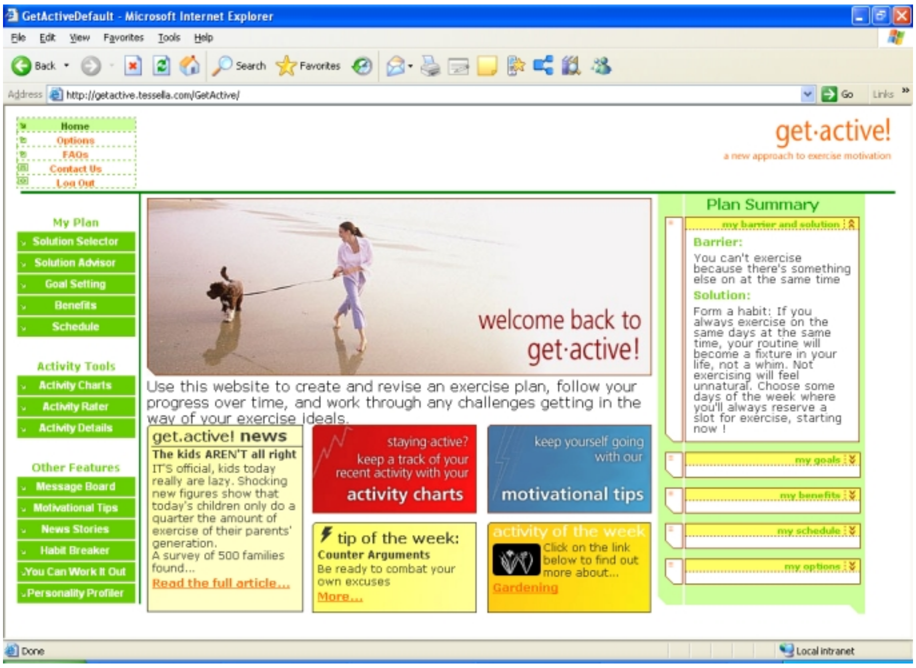


Figure 2.3: "Get Active" website (Hurling et al., 2007)

2.1.2 Social Networks

The approaches above treat the web as an improved information delivery mechanism—simply a more convenient way of delivering information than print. A significant benefit of computers, however, is that they are interactive. They create a dynamic interface between users and information.

"Web 2.0" is a realisation of this potential for dynamic information interaction. It has provided us with a new model of the web as a user-controlled social and collaborative space. Social networking apps and sites like Twitter, Facebook, Tumblr, Instagram, and Pinterest allow users to directly share physical activity information, to see how others are doing and to update others on their own activities.

There have been attempts in the research space to create social networks that are specifically directed toward health-related behaviour change. For example, Kamal et al. (2010) built a prototype social networking website where users could create their own microblogs, share recipes and photos, and track their physical activity

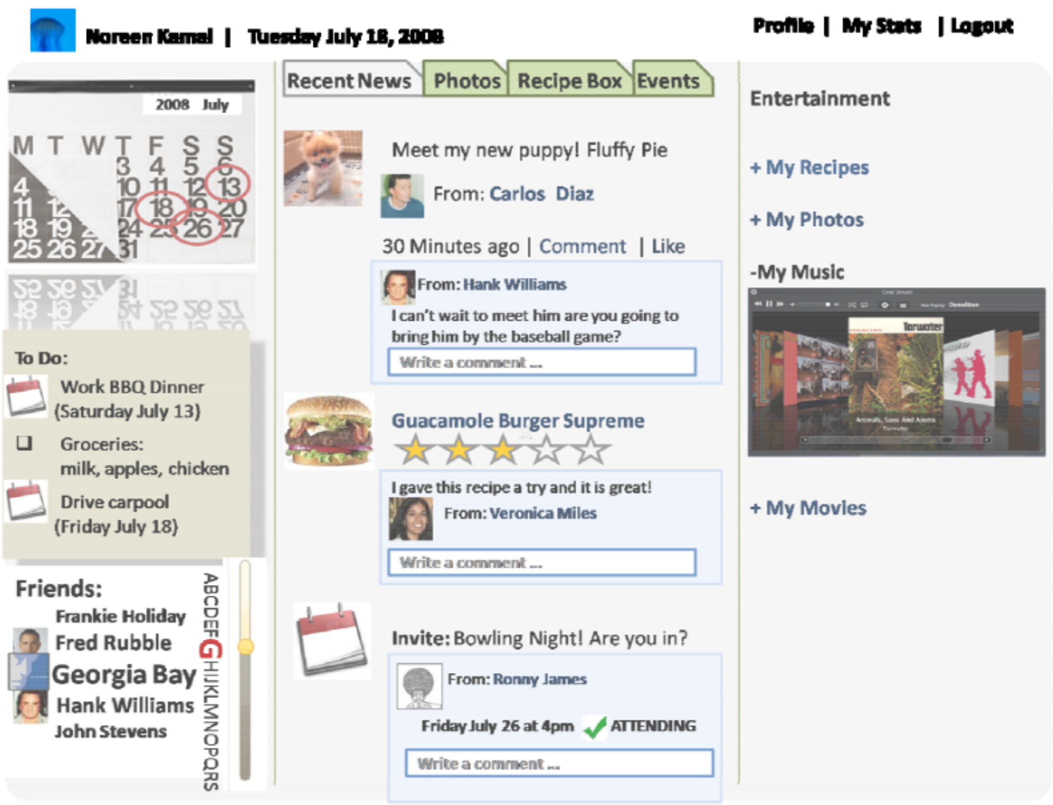


Figure 2.4: Physical activity social network (Kamal et al., 2010)

and food intake (Figure 2.4).

Baghaei et al. (2009) explored the approach of combining static content explaining healthy living with a dynamic social networking component. Their SOFA social network provided each user with a blog, activity diary, and photo gallery. Users could see which static pages others had visited, making them aware of popular content. They were also provided a forum in which to discuss healthy behaviour and seek advice from—and provide support to—other users.

Newman, Lauterbach, Munson, Resnick, and Morris (2011) argue that advertising one's success is a way of potentially gaining credit from one's peers and of motivating those peers to do better themselves. However, they note that there is a great degree of image management on social networks. That is, people want to paint a picture of themselves as happy and successful even if this is not the truth. Admitting faults and seeking help could be seen as a sign of weakness. This is especially the case considering the typical user would have a mixture of close friends and casual acquaintances in a real-life online social network, and may not feel comfortable being as open with the latter as with the former.

2.2 Self-Monitoring Approaches

"Self-monitoring" approaches use computers to collect information about an individual's behaviour and to provide a summary or processed version of this raw data back to the individual. This can be as simple as providing the user with a computer journal into which they can manually enter information, such as step counts from a pedometer, exercise performed, or meals consumed (as in Freyne et al. (2010) and Tsai et al. (2007)). It is more common in such work, however, to use electronic activity monitors that can automatically record such things as physical activity. Interactive and social elements, such as allowing the user to compare their activity with friends and to earn rewards, can enhance these approaches.

Self-monitoring approaches sit mid-way on the scale of motivation—they rely on the user's internal motivation to monitor their own behaviour, but also provide external motivators such as peer pressure and support. They sit toward the subtle end of the persuasion scale in that they mainly track and support existing activities and don't provide direct instructions to do any particular activity. The majority of existing approaches in this category can be classified as high-engagement, high-complexity approaches due to the presentation of quite detailed data back to the user and also the expectation that the user will contribute regular information to get anything out of the system.

Figure 2.5: "Houston" mobile phone app (Consolvo et al., 2006)

2.2.1 Logging and Journaling

An example of activity journaling is the "Houston" system described by Consolvo et al. (2006) (Figure 2.5). Houston consists of a pedometer and fitness journaling app running on a mobile phone. Users would enter their daily step count into the app, which would then display step trends and averages and allow the user to set a daily step goal. In a user study of Houston, participants were formed into groups of four or five and could choose to share their step count with other members of the group. The app also allowed them to view trends, averages and goals for those other participants.

Toscos et al. (2006) applied this same approach to teenage girls in a system called "Chick Clique" (Figure 2.6). Each girl was given a pedometer and asked to enter her daily step count into a program running on a PDA. Her step count would then be shared with her group of friends through their PDAs. Automated text messages

Figure 2.6: Chick Clique (Toscos et al., 2006)

were sent to the girls indicating group performance and offering praise for achieving step goals. The program also incorporated a calorie calculator and a list of "good foods" at various fast food restaurants.

Lin et al. (2006) expanded on this social approach in their "Fish'n'Steps" system (Figure 2.7). Employees in a workplace were provided with pedometers and asked to enter their daily step counts into a computer. Each user was represented on the computer screen as a fish in a virtual fish tank. If a user was reaching their physical activity goal, their fish would grow. In addition the fish's facial expression would change between sad, angry, or happy depending on the user's progress toward their daily goal. In the group version of the interface, multiple users' fish would occupy the same tank. If one user was letting down the team by failing to reach their daily goals, then decorations would be removed from the tank and the water would become murky.

The intended motivational effect of these approaches is twofold: that users will be motivated to be more physically active by monitoring their own activity levels, and

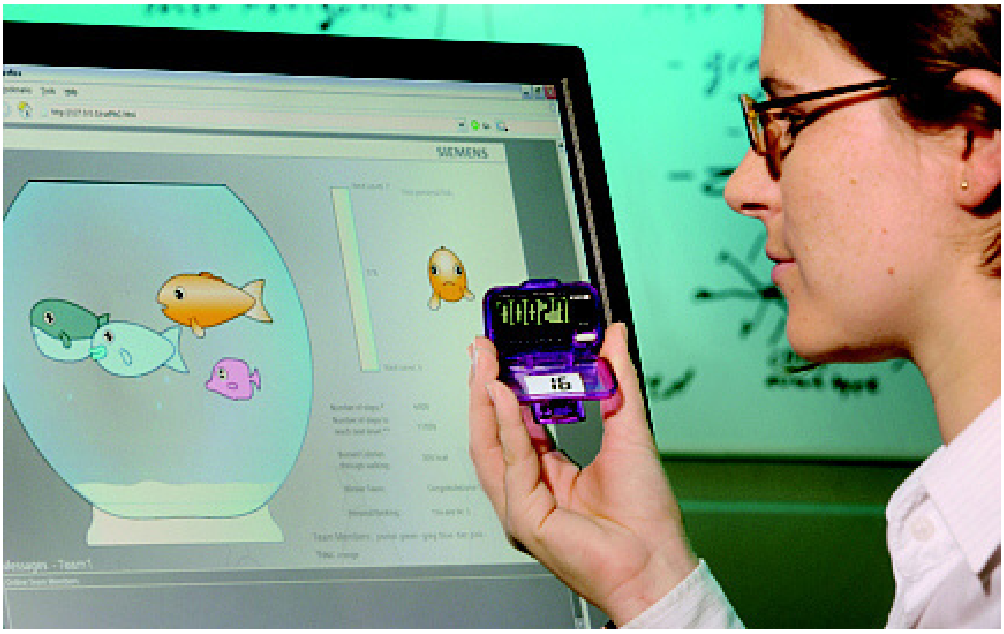


Figure 2.7: Fish'n'Steps (Lin et al., 2006)

that they will be motivated and help to motivate others through the sharing of activity information to form a collaborative 'virtual space' that all feel a stake in maintaining.

The use of pedometers may also be seen in health interventions that fall under the category of "informational" approaches. However, informational approaches mostly use pedometers as outcome measures—they are simply a way to measure the effectiveness of the approach and are not an inherent part of it. The expectation is that if the information provided is having an effect, then this should be reflected in increased step counts. Self-monitoring approaches, on the other hand, use pedometers as a core component of the intervention itself. In the case of Fish'n'Steps, for example, participants' step counts directly influenced the nature of the ongoing persuasive display, creating a feedback loop where steps changed the intervention itself. The pedometer is, therefore, an integral part of the intervention.

Whilst pedometers have been used for decades and are well understood by users, they do have a number of limitations. They are designed purely to measure the number of steps taken when walking and may not accurately capture other forms of physical activity. With the exception of a small number of models, they cannot interface with a computer system directly. The user is required to manually enter step counts into a tracking program—a potentially frustrating and error-prone task.

2.2.2 Activity Monitors

Recently it has become common to replace the pedometer with an "activity monitor"—a small wearable computer with a motion sensor that logs the duration and intensity of the wearer's movement throughout the day (and sometimes also during sleep). Activity monitors can collect a wider range of data and can automatically transmit those data to a computer system, rather than relying on manual entry.

The "motion sensor" in an activity monitor, in most cases, is actually a device called an "accelerometer", capable of recording the magnitude of acceleration in all three axes of three-dimensional space. These accelerometers are sampled at regular intervals, usually about 50–100 times per second (50–100 Hz). The readings are then passed through a filtering process to remove noise and DC components (mainly the constant acceleration due to Earth's gravity). They can then be integrated to determine velocity with respect to time, and further integrated to find distance with respect to time.

These data may then be used to draw conclusions about the wearer's level of physical activity. More movement is evidence that the user is physically active, whereas less movement is an indicator of sedentary behaviour. Some interventions simply turn this raw data into a unitless number that increases with greater physical activity (for example, Nike's "NikeFuel" system). Others pass the data into a classifier algorithm which attempts to determine the nature of the user's activity (walking, running, sitting). The data can then be converted into a unitary measure such as steps taken or calories burned.

An example of an intervention in the literature incorporating an activity monitor

Figure 2.8: UbiFit Garden (Consolvo et al., 2008)

with a classifier is "UbiFit Garden" (Consolvo et al., 2008) (Figure 2.8). Users wore a "mobile sensing platform" (MSP) module incorporating an accelerometer and activity classifier software. The MSP determined the likely type of activity the user was undertaking (walking, running, cycling, using an elliptical trainer or stair machine) and transmitted this to an activity journal running on the user's mobile phone. Users were able to manually enter other activities not detected by the classifier (such as swimming). Users' physical activities were represented on the phone's screen saver using a garden metaphor. As the user did more exercise, the flowers in their virtual garden would grow and become more numerous. Butterflies would appear to signify goals that had been achieved.

At present there is a variety of commercially-produced activity monitors. A common feature of all these monitors is the ability to access relatively detailed, or at least quantified, fitness data. Some, like the various Fitbit devices (Figure 2.9) and FuelBand, incorporate a simple display showing steps, calories, or activity "points". Others, like the UP!, have no display and rely entirely on the user's smartphone or computer to provide feedback. The UP! needs to be plugged into a phone or computer to download data. The various Fitbit devices, FuelBand, and a number of others use Bluetooth or proprietary wireless protocols. Misfit Wearables' Shine uses

Figure 2.9: Fitbit One Activity Tracker (Fitbit Inc.)

a novel magnetic coupling to transfer data using a smartphone's magnetometer.

2.2.3 Sensing Technologies

Although activity monitors can detect a wider range of activities than just steps, there are still limitations inherent in the sensing technologies used. In calculating energy expenditure using accelerometry, it is important to know where on the body the accelerometer is located in order to determine an acceleration-to-expenditure mapping. Designers may intend for an activity monitor to be worn in a particular location on the user's body, and develop signal analysis code based on this intention, but the monitor could still be worn in a completely arbitrary location at the whim of the user. Even if the designer could guarantee the monitor would be worn in a certain location, there is still a margin of error which is better for some locations and worse for others.

Fujiki, Tsiamyrtzis, and Pavlidis (2009) equipped users with a three-axis accelerometer and asked them to walk and run on a treadmill whilst connected to a gas analyser. They showed that placing the accelerometer closest to the user's centre of mass (near the waist) yielded the best correlation between accelerations and calories burnt. The wrist (perhaps the next most common location used) yielded inferior results. It was still possible to define a relationship between acceleration and calories burned, but the degree of error was higher.

Figure 2.10: Basis Band (Basis)

Even if an acceptable regression between acceleration and energy expenditure is established, accuracy is still affected by the presence of variables that cannot be measured. For example, imagine a user walking with an accelerometer attached to the wrist. An activity classifier algorithm may be able to determine, from the cadence of the wearer's arm, that they are walking. The classifier may also be able to determine the speed or intensity of walking from the magnitude of detected accelerations. However, it is difficult to determine if the user is walking up or down a hill from the movement of the arm alone—one involves higher energy expenditure than the other but the classifier may not be able to tell them apart.

One way to address this problem is to use additional sensors or contextual cues. The Basis Band, for example, incorporates sensors to measure heart rate, perspiration, and heat flux (Basis, 2014) (Figure 2.10). The Fitbit One has an altimeter to detect "steps climbed" (Fitbit, 2014b). The Garmin Forerunner line of fitness watches has a GPS receiver to track the wearer's location and speed, with some models having a "foot pod" accelerometer to measure cadence (Garmin, 2014). Maitland et al. (2006) used signal strength from mobile phone towers to track location and speed in order to classify activity as walking, running, or driving. Similarly, MacLellan and Baillie (2008) used an activity monitor and GPS to determine posture and transport mode. Chuah and Sample (2011) used the presence of WiFi access points to determine location.

Figure 2.11: BodyMedia Fit (BodyMedia)

Additional sensors are useful, however there is a tension between designing for accurate sensing and designing for usability. Fitbit, for example, have experimented with both waist-worn and wrist-worn sensors and are now biased towards wrist-worn sensors, possibly because users find the wrist to be a more convenient location to wear and view a device. Consolvo et al. (2006) found waist-worn devices are less convenient for women as their clothing can lack a sensible place to secure a device. BodyMedia decided the best results were obtained when a device was worn on the upper arm, but this is an unusual and unnatural place to attach anything to one's body in terms of current fashion. (BodyMedia, 2014) (Figure 2.11)

Location sensing systems such as GPS, cell tower triangulation, and WiFi signal detection can suffer from reliability issues. GPS does not work well indoors and in so-called "urban canyons". The accuracy of cell tower triangulation varies wildly depending on cell density and can sometimes return a location with an error of several kilometres (although newer cellular systems with higher cell density may improve this). WiFi detection assumes conveniently located access points. In any case, all of these systems are useless in determining energy expenditure if the user is stationary, e.g. on a treadmill or stationary bike.

At least with sensing technologies presented in the computing literature, it is usually possible to independently evaluate efficacy and accuracy. Commercially available solutions almost always employ "trade secret" algorithms developed by companies' in-house scientists and engineers. Fitbit claim their accelerometer-based activity monitors are accurate, yet do not present their algorithms for public scrutiny. Researchers using commercially-available devices in physical activity studies are left to conduct their own assessments of efficacy prior to deciding to employ a particular technology as part of their research.

One such assessment was undertaken by Guo, Li, Kankanhalli, and Brown (2013). They compared several commercially-available devices, including the Fitbit One, Nike+ FuelBand, Nike+ SportsBand, two pedometers and the "Moves" app for iPhone. They asked participants to walk around a track whilst wearing all the devices simultaneously, and compared the steps and distances recorded by each device with the ground truth of the actual distances travelled and numbers of steps taken. One participant also wore the Fitbit One and Nike+ FuelBand simultaneously in real-world situations for several weeks.

In the walking track comparison, the Fitbit was the most accurate in both steps and distance measured, with an average 1.05% error in steps measured and 3.72% error in distance, compared to the ground truths. The wrist-worn Nike+ devices were less accurate, with an average 7.79% error in steps measured and an 11.17% error in distance. The step error of the pedometers was 4.42% for the best and 13.10% for the worst. The iPhone-based "Moves" app had the worst steps accuracy at an average 27.28% error. The real-world study showed a correlation between Fitbit steps and distance, and FuelBand steps, distance and "Nike Fuel", however there was no ground truth with which to compare these data individually.

As Fujiki et al. (2009) discussed, the wrist clearly yields less accurate measurements that the waist, even though it may be a more comfortable or practical location to wear a device. The accuracy of mobile-phone based sensing will depend on how the phone is carried (I discuss this in the next section).

Clearly devices such as the Fitbit and FuelBand are reasonably accurate when tested in controlled conditions (regular walking around a flat track), and it is possible to measure accuracy objectively when there is a ground truth. The intention, however, is that they be used in real-world situations, where a user's physical activity may not conform to the narrow range of activities understood by the device's algorithms, and where users may wear the devices differently from day-to-day. Given these uncontrollable variables, and the lack of a ground truth, it will always be difficult to say with any certainty whether any of these devices are truly accurate in measuring actual lifestyle activity.

2.2.4 Smartphones as Sensors

Rather than equipping the user with a dedicated activity monitor, some companies have developed software to use the accelerometer in the user's smartphone as an activity monitor. On the face of it this makes sense—65% of people in Australia already have smartphones (Google, 2013). Rather than requiring users to buy another device they must remember to use and charge, it seems practical to allow them to use a device they already own.

Unfortunately, accurate mobile phone accelerometry poses additional challenges. As previously discussed, activity monitors are usually designed such that they imply a particular body location through their form (commonly the wrist). Mobile phones do not imply any particular body location—they can be carried in any arbitrary location at any time. Wear location will most likely depend on such factors as the user's gender and what type of clothing they're wearing—a man wearing jeans might carry his phone in his pocket (a good location—near the centre of mass), while a woman wearing a dress without pockets may carry her phone in her handbag (a less ideal location in terms of converting accelerations into a measure of energy expenditure).

Assuming wear location is known and can be compensated for, there is a baser requirement that the user carries their phone with them when they are physically active. Research shows this is not necessarily the case. Dey et al. (2011) quantified the amount of time a group of people had their phones within arm's reach, in the same room, in another room/location, or switched off (Figure 2.12). They found

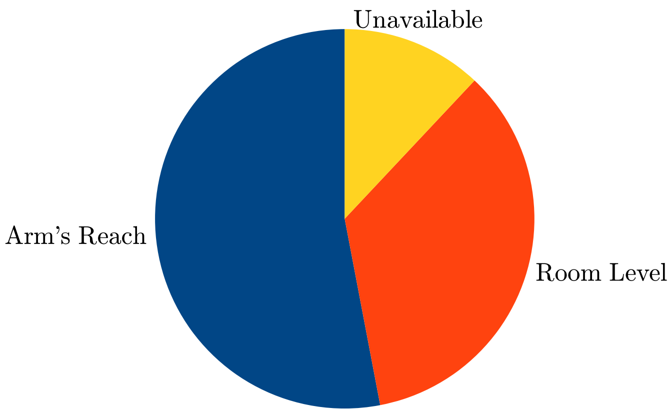


Figure 2.12: Proportion of time users have their phone within arms' reach or elsewhere (Dey et al., 2011)

that, for their user group, almost half the time the users did not have their phones within arm's reach. They did not discriminate between a phone being within arm's reach and on the user's body. However, even assuming the user had the phone on their body in all "arm's reach" cases, the implications for activity sensing are clear. The phone's accelerometer cannot provide a true representation of the user's physical activity if the user doesn't have the phone on their person for a significant amount of the day. Thus the focus in the research and commercial realms on using dedicated wearable devices rather than mobile phones as sensing platforms, and the popularity of dedicated devices such as the Fitbit Flex.

2.3 Direct Approaches

Direct approaches are distinguished from informational and self-monitoring approaches in that they engage people directly in the behaviours the intervention wishes to support, as opposed to simply encouraging or supporting engagement. In the context of physical activity, this includes such things as the game Wii Fit for Nintendo Wii. Physical activity is core, and indeed required, to engage with and play this game. However, active games are only one type of direct approach in this space. Others involve gamification of traditional exercise activities or even associating sedentary activities with physical activity, and modifying existing environments to make them more supportive of physical activity.

Direct approaches rely on external motivation—the approach itself directly prompts or causes the user to engage in physical activity. Exergaming and gamification of physical activities apply explicit persuasion, telling the user what to do unequivocally. Environmental modifications apply more subtle suggestion, promoting a course of action but not directly instructing. Direct approaches tend to fall in the middle of the engagement scale, and have low to medium complexity depending usually on the level of gamification.

2.3.1 Movement and Exertion as a Game Input

Some direct approaches use bodily movement and/or exertion as an input to a computer game. This is not a new concept—Atari's Joyboard from 1982 is strikingly similar to the Nintendo Wii's Balance Board (AtariAge, 2014), and Konami's Dance Dance Revolution arcade game has been around since 1998 (Andrews, 2007). The Wii, however, was the first gaming system to bring the concept into the mainstream, and this concept has now been copied and further developed by other companies.

In order to play Nintendo Wii games, users hold a remote control-shaped "Wiimote" which incorporates an accelerometer and angular rate sensor to track the motion of the user's hand. Infra-red LEDs at the end of the Wiimote allow a "sensor bar" mounted on the user's television to track its orientation with respect to the screen. A common game mechanic involves the user swinging the Wiimote to control their avatar in the game. The avatar could swing a baseball bat, putt a golf ball, or punch an opponent in response to the motion of the user's hand.

Since the original Wii's release, Sony has introduced the PS Move control system for the PlayStation 3, which uses a combination of motion sensors and computer vision to detect the position of players' controllers (Sony Computer Entertainment America, 2013). Microsoft introduced Kinect, a sensor bar placed on top of the

Figure 2.13: PlayMATE! (Berkovsky et al., 2012)

user's television containing depth-sensing cameras (Figure 2.14). Kinect allows so-called "controllerless" play—rather than having to hold a physical controller the user simply moves their legs, arms and hands to control their in-game character (Microsoft, 2014).

Berkovsky et al. (2012) explored the possibility of integrating exertion into an existing sedentary game. Neverball is an open-source game where the player guides a ball through a maze, attempting to reach the end within a time limit. In the activity-augmented version of the game, players were equipped with a three-axis accelerometer (Figure 2.13) and told to jump to gain extra time. The gameplay mechanic was fundamentally altered as movement became a requirement to complete levels. Importantly, this new requirement for exertion did not affect players' subjective enjoyment of the game.

In some games physical activity is made more central to the gameplay. For example, Nintendo's Pokémon Pikachu and Pokémon Pikachu 2 hand-held games incorporated a pedometer feature. Every 20 steps the user earned a "Watt" that could be used to buy presents for the virtual Pikachu character living on the device or gambled for more Watts. Nintendo later bundled a standalone pedometer, the Pokéwalker,

Figure 2.14: XBOX Kinect (Microsoft)

with copies of their Pokémon HeartGold and SoulSilver games for the Nintendo DS handheld platform. Players could download a Pokémon character from the game via infra-red to the Pokéwalker, where the character would earn experience based on the number of steps the player took in a day. The player could also earn Watts and win special items (Thomas, 2013).

Similar approaches in the literature include a mobile game by Fujiki et al. (2008), where players could bank "points" awarded as a result of physical activity to later use to buy clues to solve Sudoku puzzles. Nenonen et al. (2007) proposed linking physical activity to in-game strategy—in their virtual biathlon game a faster heart rate resulted in increased skiing speed. However in the shooting portion of the biathlon a higher heart rate resulted in lower accuracy. Therefore a player needed to balance the need for faster skiing against the need for high shooting accuracy.

This "active" gaming does not necessarily deliver any health benefits over traditional exercise activities. In a meta-analysis of a number of active gaming papers, Peng, Lin, and Crouse (2011) found that active games produced a similar effect size to light- to moderate-intensity physical activity, but that the nature of the activity was important. Games involving mostly upper-body movement resulted in less energy expenditure than those that also incorporated lower-body movement.

Even accepting some active games involve non-trivial energy expenditure, any health benefits will only be realised if people remain engaged with the game for more than a brief period of time. In practice, this has proven not to be the case. Owens, Garner, Loftin, van Blerk, and Ermin (2011) provided a Nintendo Wii with Wii Fit software to eight families over a three month period. At the end of the study, families as a whole showed no significant increase in daily physical activity, muscular fitness, flexibility, balance or body composition. Participants' use of Wii Fit declined from an average of 22 minutes per day in the first six weeks of the study to an average of four minutes per day in the second six weeks.

2.3.2 Exergaming

F. Mueller, Agamanolis, and Picard (2003) posed a distinction between games that simply use motion as an input and games that require real exertion. The latter are commonly termed "exergames" and employ what they called "exertion interfaces"—those that deliberately require "intense physical effort". EA Sports Active for Nintendo Wii is an example of such a game—the running and resistance training needed to properly play the game require true sweat-producing exertion. The aforementioned Dance Dance Revolution game is another example—the stomping on arrows integral to this game is a physically demanding task, especially at higher levels of difficulty.

There are a number of examples in the literature of games employing "exertion interfaces". F. F. Mueller and Agamanolis (2005) developed a full-sized version of the popular computer game "Breakout" (Figure 2.15). Players kicked a ball at a projection wall displaying virtual bricks. A sensor system determined the location on the wall where the ball struck and deleted the bricks appropriately. Overlaid on

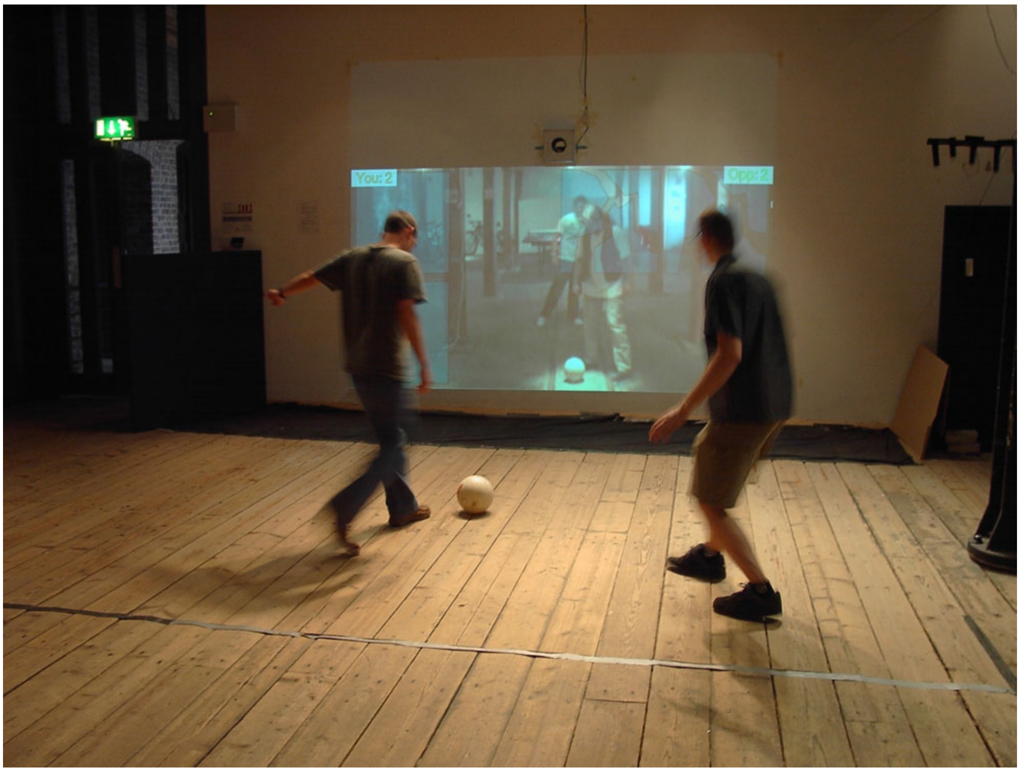


Figure 2.15: Breakout for Two (F. F. Mueller & Agamanolis, 2005)

this could be a video image of a remote player, allowing two people to compete to knock out the same bricks.

Cheok et al. (2004) used augmented reality technology to create a unique exergame called “Human Pacman” (Figure 2.16). Players would chase each other around real-world spaces wearing a head-mounted display that overlaid video of the real world with game elements such as “power pills”. One player would be Pacman and would be chased by other players acting as the ghosts.

Some exergames specifically involve gamification of traditional exercise activities, usually in an attempt to make them more interactive, interesting or engaging. For example Mokka, Väätänen, Heinilä, and Välkkynen (2003), Moloney (2010) and Yim and Graham (2007) developed separate systems where a stationary bike with a speed sensor was placed in front of a computer screen projecting a virtual landscape. Users could pedal the bike to move through the landscape. In Yim and Graham

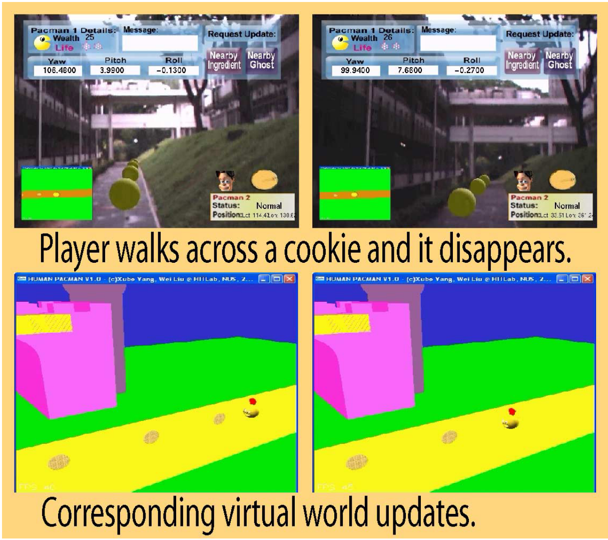


Figure 2.16: Human Pacman (Cheok et al., 2004)

the landscape was purely virtual and players were required to collect resources to build a virtual village. Moloney and Mokka et al. used real-world imagery and map data to create a landscape for the user, with Moloney providing the user with a Wii remote to allow them to rotate their perspective. Mokka et al. and Yim and Graham provided realistic force feedback when users rode uphill.

There have been similar approaches in the commercial realm. As far back as 1982 Atari were developing an exercycle game controller as part of their “Project Puffer” (Figure 2.17), although it was never brought to market (due to Atari’s unfortunate bankruptcy) (Boing Boing, 2008). Suncom’s “Aerobics Joystick” from the same era involved a user pedalling a stationary bike to activate a game’s “fire” button whilst the user maintained directional control using a traditional joystick (AtariHQ, 2005). Another similar controller was the Autodesk HighCycle. More recently there have been the Cat Eye “Gamebike”, the Fortius Trainer and others (Tacx, 2014).

An iconic dance game in the commercial space is Dance Dance Revolution from Konami (Figure 2.18). In DDR a series of arrows scroll up a video screen set to music. Players must jump on the appropriate arrows on a floor pad (usually in time to the beat of the music) to score points. Various arcade and console ver-

Figure 2.17: Atari Project Puffer Prototype (Atari Gaming Headquarters)

sions of the game have been produced since its release in 1998, many allowing for multi-player modes where two or more people can compete with each other based on accuracy (Andrews, 2007). DDR floor mats have often been re-purposed as non-game exertion interfaces, for example Meyers, Brush, Drucker, Smith, and Czerwinski (2006) developed a system to allow users to read emails and scroll through photos by stomping on arrows.

Walking and running have also been gamified. Chuah and Sample (2011) developed "fitness tour"—a mobile phone application that provided users with random walking or running routes. The user's phone would detect the presence of certain wireless access points along the route to provide "proofs" of the user's route time and location. The phone's camera was also used to determine the user's heart rate by taking an optical pulse reading of their index finger, which combined with the location proofs allowed calorie burn to be approximated. Campbell, Ngo, and Fogarty (2008) considered the idea of a virtual tour where a person's real-life running caused their avatar to move across a computer generated map.

Figure 2.18: Dance Dance Revolution (Wikipedia—SPUI)

2.3.3 Environmental Modification

Another direct approach is environmental modification. This involves modifying users' environments in such a way that physical activity becomes a required aspect of some everyday sedentary task (as opposed to making it optional or simply encouraging it).

For example, Nawyn, Intille, and Larson (2006) re-implemented the television with a view to making TV watching a more active experience. During ad-breaks on-screen prompts would appear, prompting viewers to get up and perform short physical activity challenges. The remote control was also re-designed with a view to reduce channel surfing, and viewers were asked to pre-commit to a limit on minutes of television each night, reducing the potential negative impact of the activity.

Chaudhari and Clark took a more direct approach with their "Telecycle" interface, linking a stationary bike directly to a TV and making the viewer cycle in order to keep watching. If the user cycled too slowly the image on the screen became fuzzy. Faster cycling resulted in a sharper picture (Fogg, 2003).

Miller, Rich, and Davis (2009) attached a series of LED “fireflies” to walls in a building, creating a path between lift doors on two different levels via a stairway. When a user pressed the lift call button the fireflies would light a sequence toward the stairs, drawing the user’s attention to the idea of stair use. The user could chase the fireflies down the stairs and if they reached the other level within a certain period of time the lights would flash in a “reward” pattern. The intention of Miller et al. was to introduce a level of fun into using the stairs and to provide people with a reason to use them over the lift. Stairwells can be sterile and boring places but by making them as interesting or more interesting than lifts we may encourage more people to use them. The health benefits in this case become more of a side effect of engaging in an enjoyable activity.

Rogers et al. (2010) aimed more toward gentle social persuasion using a series of public ambient displays. They experimented with embedding LEDs into the floor of a building. When users walked toward the lift, the LEDs would light a path along the floor toward the stairs (“follow the lights”) (Figure 2.19). They metered the number of people using the stairs and the lift and visualised this data using an ambient display of coloured spheres in the lobby that would rise and fall depending on which mode of transport was more prevalent (“clouds”). A series of large wall-mounted screens displayed pie charts graphing historical lift usage (“the history”). Their “follow the lights” display exerts a sort of social pressure, making the subtle statement “you really should be using the stairs” when they appear. Similarly their “Clouds” sphere display and “History” pie charts work to create a new social norm. Any trend towards using the stairs is reflected visibly in a way that makes others feel they should consider using them too.

The idea of making active options fun has also been used to encourage stair use over escalator use. In 2009 a marketing agency working for a major European car company created the “Piano Keys” video. They selected a stairway next to an escalator in a Swedish subway and augmented the stairs with electronic pads to create the appearance of keys on a piano (Figure 2.20). When commuters walked

Figure 2.19: Twinkly Lights (Rogers et al., 2010)

up and down the stairs they lit up and played musical notes. The creators of the video claimed a 66% increase in stair usage vs. escalator usage after the keys were installed (Volkswagen, 2009).

A further example of environmental modification is the use of computers to persuade people to use more active forms of transport (walking or cycling) over sedentary ones. Singh and Mathew (2007) augmented bus stop timetables on a university campus with an interactive map. The map showed walking times and distances between different points on campus and the number of calories that could be burned walking between them. It contrasted walking times with how long it would take to travel by bus (calculated dynamically with buses' current GPS locations). The hope was that students may decide to walk if they understood how the time commitment would compare to a bus trip and if the health benefits of the walk were made clear.

Lim et al. (2011) had the unique idea of modifying footwear to motivate the user to be more physically active. Their "Pediluma" device strapped to the top of a user's shoe and illuminated when the user walked or ran (Figure 2.21). The device would stay lit for a period of time after the user stopped exercising before fading to

Figure 2.20: Piano Stairs (Volkswagen, 2009)

off. Their intentions were two-fold: that the user would be motivated to be more physically active in order to see their shoe light up, and that the conspicuous light would prompt discussions with others around exercise.

This approach of integrating an ambient display into a piece of wearable technology was previously explored by Williams, Farnham, and Counts (2006), albeit not in a physical activity context. They designed a bracelet—“Damage”—that allowed the wearer to send messages to, and receive messages from, others in a group of friends. To send a message the user would close a snap on their bracelet, causing a particular coloured LED to illuminate on group members’ bracelets. Each bracelet had a group LED that became incrementally brighter as messages were sent amongst the group.

Their work was itself based on that of Kikin-Gil (2005), who developed a charm bracelet—“BuddyBeads”—consisting of different touch-sensitive beads which, when pressed, would send messages to other users’ bracelets. Their intention was to allow a group of teenage girls to communicate their emotional states to one another at a distance, to support socialisation and identity.

An important aspect of Pediluma (Lim et al., 2011) is that the ambient display is

Figure 2.21: Pediluma (Lim et al., 2011)

intended to be viewed by other people as well as the wearer. The conspicuous nature of the display is intended to draw attention and comments from others. This is in contrast to other approaches where it is assumed that the user will want to keep the information displayed private. Damage (Williams et al., 2006), for example, was designed to be intentionally unreadable to observers who did not understand the personal and social meanings of the colour codes used. The same was the case for BuddyBeads (Kikin-Gil, 2005)—wearers devised a “secret private code” ahead of time to allow them to communicate their emotional states in such a way that the messages couldn’t be understood by others.

2.4 Engagement and Complexity

I defined a two-dimensional space, with complexity on one axis and engagement on the other. I then placed the approaches previously discussed into this space, based on what I judged their properties to be in each dimension (Figure 2.22. Most approaches are clustered toward the high engagement, high complexity region, with environmental modification ranking lowest on both engagement and complexity scales. The interfaces employed in the majority of existing interventions are

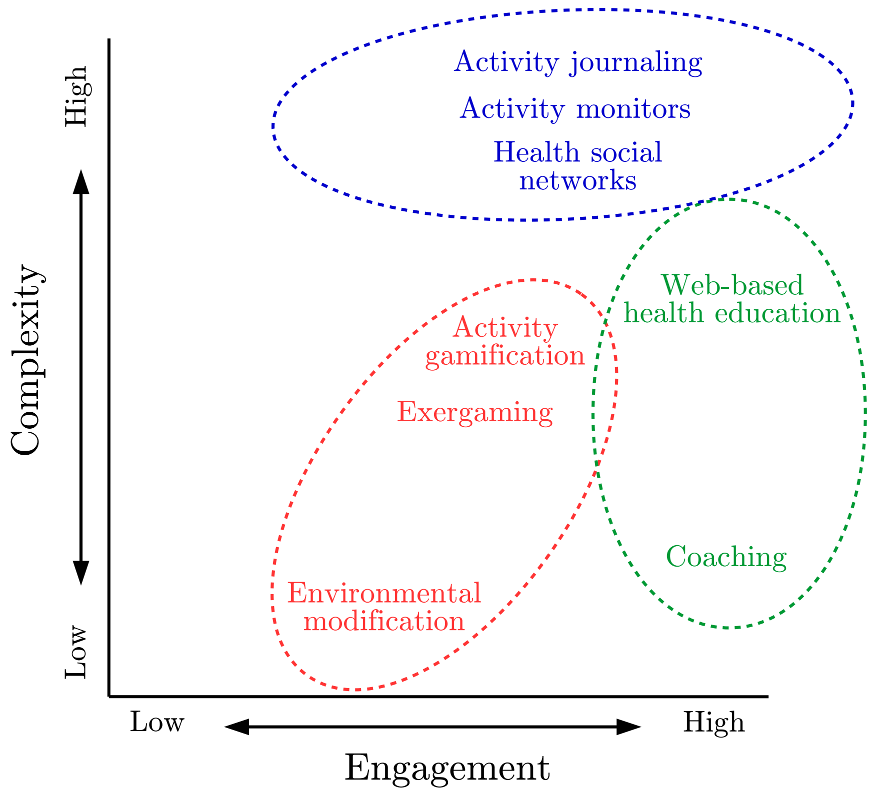


Figure 2.22: Specific interventions arranged by complexity and engagement

heavy on words, numbers, and graphs and delivered through direct interaction with a phone, website, computer screen or gaming system. Less attention has been given to lower engagement, lower complexity interfaces, even though they have a number of unique properties and potential benefits that make them well worth further study.

Ambient displays are a well-known type of low-complexity, low-engagement interface. These are displays that place information into the user's environment in such a way that it can be passively consumed. In their 1996 paper "The Coming Age of Calm Technology", Mark Weiser and John Seely Brown coined the term "calm technology" to describe such interfaces. They presented the example of the "Dangling String" by artist Natalie Jeremijenko—a string hung from the ceiling that danced around with more or less vigour depending on the rate of traffic on a local area network (Figure 2.23).

Such technology was encalming, they argued, because it stayed in the periphery of

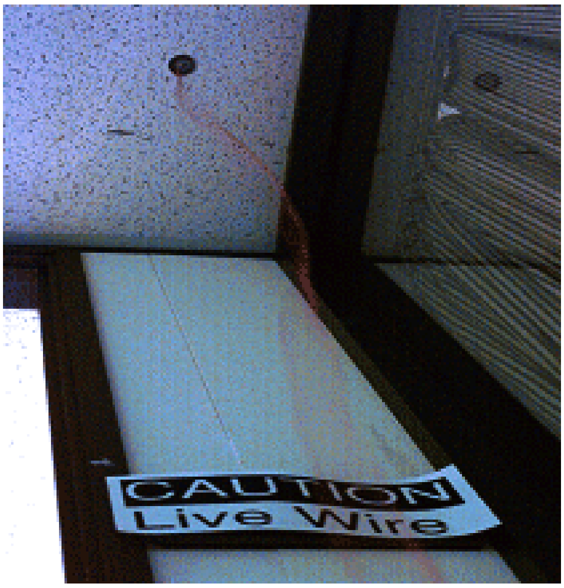


Figure 2.23: Natalie Jeremijenko's "Dangling String" ambient display (Weiser & Brown, 1996)

the user's vision. It allowed them to be aware of some information (in this case how busy the network was) without having to constantly focus on that information as they would if it were presented using numbers or words on a computer screen. There is only a certain amount of information that humans can focus on in the centre of their attention at any one time. By placing some of this information in the user's periphery, it is possible to increase the overall amount of information that can be consumed simultaneously.

Weiser and Seely Brown proposed a user behaviour called "re-centring". This is where the user notices some peripheral indication, consciously decides to move the interface to the centre of their attention and is then empowered to take some action. For example a network administrator, upon noticing out of the corner of their eye that the dangling string is gyrating violently, might decide to open a more detailed network monitoring application on their computer. They may find that someone is deliberately overwhelming the network and take some action to curtail that behaviour. Calm computing is empowering because it liberates the administrator from having to consciously monitor network traffic. Monitoring is moved into the periphery, allowing other things to occupy the centre of attention, while important indications in the periphery can still prompt action when needed.

Some of the interventions mentioned previously incorporate ambient displays to assist the user to monitor their level of physical activity. In the Fish'n'Steps system, the fishbowl is an ambient display—users can assess their own level of physical activity and that of others in their group with a simple glance at the fishbowl. In UbiFit Garden, a glance at the mobile phone's garden metaphor shows the user whether they are meeting their exercise goals. If the user doesn't like what they see, then the re-centring behaviour might be making time to be more physically active or reflecting on past performance and future intentions.

Mankoff et al. (2003) presented a set of heuristics for evaluating ambient displays. These described properties an ambient display should have, and included:

- Convey "just enough" information.
- Add minimal cognitive load.
- Be intuitive.

The ambient displays previously described aim to achieve this intuitive presentation of information—the size and decorations of a fish or the number of flowers in a garden are simple metaphors for the amount of physical activity performed. These metaphors try to remain neutral of any particular social or cultural context, and to require very little or no training or education to understand. Larger fish or more flowers should be understood to mean a greater level of physical activity, regardless of the user's level of literacy or numeracy, or their ethnicity.

Contrast this with an informational or self-monitoring representation that presents information in terms of calories or kilojoules, miles or kilometres. There is an assumption that the user understands what a calorie, kilojoule, mile or kilometre is—this pre-supposes the user is numerate and from a culture in which the appropriate units (be they metric, imperial or SI) are in common use. If the user is familiar with the units, there is a further assumption that they can convert some value in those units into something meaningful. Knowing how many calories or kilojoules to consume each day, or how many miles or kilometres to run, requires a degree of health literacy around appropriate exercise and nutrition behaviours.

Exercise ambient displays seek to add minimal cognitive load to the user. Looking at the state of a virtual fish or garden, and converting this visual information into activity information, should be an almost subconscious process similar to looking at a red traffic light and thinking “stop”. Looking at a step count or calorie count requires additional computation—the user must compare the value shown with some goal or limit in order to assess their current performance. Even if this calculation is done automatically, the user will still need to consciously consider a graph or series of numbers representing individual days’ activity to observe trends over time. This is more mentally demanding (and again, assumes a greater level of numeracy) than simply watching the progression of one’s fish or garden over time (Burns et al., 2012c).

These aims extend to group or social elements of a display. In the group version of Fish’n’Steps, the clarity of the water and number of decorations in the fish tank should provide a more intuitive representation of the performance of the group than if the same information had been presented in numerical form.

Intuitive displays that impose minimal cognitive load are potentially more approachable for less engaged users. The tradeoff is, however, that ambient displays have a lower bandwidth than other types of display (the heuristic of Mankoff et al. (2003) that they should present “just enough” information). A display using words, numbers and complex graphs can convey more information overall than a simple ambient metaphor such as the size of a fish.

Direct approaches involving applying physical activity to games or sedentary activities and informational approaches involving coaching may also impose less com-

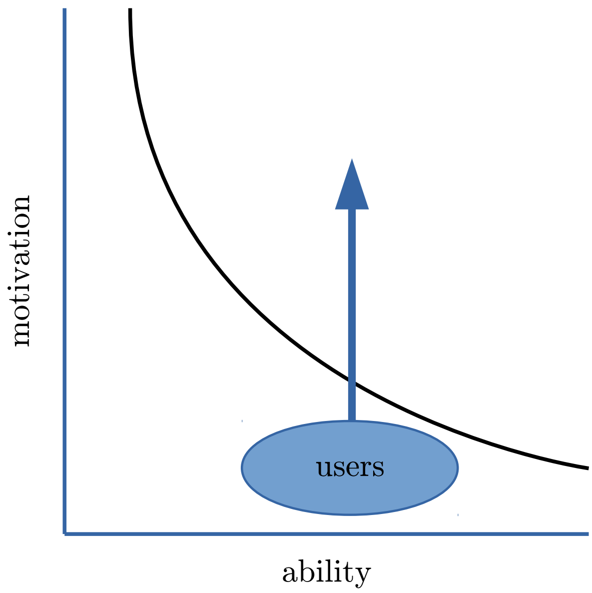


Figure 2.24: Most users have high ability to engage in exercise but lack motivation

plexity on the user, but engagement demands are still high. As well as the form of motivation provided by the intervention itself there is another form of motivation that needs to be acknowledged: the user's inner motivation to engage with an intervention. Even low-complexity interventions will fail if the engagement requirements are greater than the motivation of the user to engage.

Fogg proposes that for behaviour change to occur a person must be motivated to change, have the ability to change and there must be a trigger (or catalyst) (Fogg, 2009) (Figure 2.24). Barring illness or disability, everyone who is not active enough has the ability to be more physically active. The previously outlined interventions all attempt to augment or increase an individual's motivation and to act as the trigger for change. They each vary in the source and nature of the motivation and persuasion used to achieve those aims.

In Burns et al. (2013), I proposed extending Fogg's behaviour model to "meta-behaviour"—the particular behaviour of engaging with a computer system intended to promote changing other behaviours. The meta-behaviour of regular use of an intervention is a requirement for that intervention to produce an increase in physical

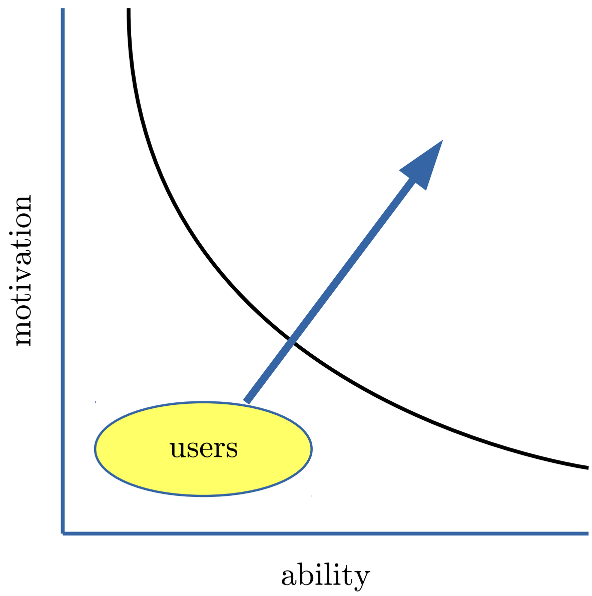


Figure 2.25: The user engagement challenge is to create interfaces that users have the ability and motivation to use

activity, regardless of how efficacious the intervention itself is. Again, there are three components: ability, motivation and a trigger (Figure 2.25). The user must have the ability to use the computer system and comprehend the information presented, the motivation to commit the time to use it regularly and a trigger to use it.

Unfortunately the reliance on a mobile phone or fixed screen to create an ambient display weakens users' ability and motivation to engage in "meta-behaviour". Fish'n'Steps assumes the user is interacting either with the dedicated kiosk or is looking at the fish bowl on their computer, and is therefore ambient only in limited circumstances. UbiFit Garden is more portable (as the display is on a device the user carries with them) however, again, it is assumed that the user is interacting with their phone for some other reason in order for them to view the ambient display. The frequency at which these displays will be seen is therefore linked to other unrelated behaviours which could vary significantly between users.

Further, in both cases it is assumed that the user is viewing the ambient display at a time when re-centring is possible. That is, when the user sees their fish is smaller than they would like or their garden doesn't have enough flowers that they are in a state where they are prepared to be physically active or to think about exercise. In the case of Fish'n'Steps the intervention was centred around an office, which by their nature tend to be sedentary places where the individual has limited discretion to come and go freely during the day. In the case of UbiFit Garden, interaction with a phone is an increasingly popular sedentary activity, and this is especially so with the growing popularity of mobile phone gaming.

To ensure that ambient displays are as effective as possible at motivating behaviour change, it is necessary to reduce or eliminate pre-requisites to engagement. Ideally displays should be persistently visible by the user and should be visible at times and in situations where the user is able to re-centre and take action in response to the information presented. One obvious approach is to create an ambient display that the user can wear (for example, Pediluma (Lim et al., 2011), Damage (Williams et al., 2006) or BuddyBeads (Kikin-Gil, 2005)). The display is then visible to the user whenever they are wearing it. The hope would be that the user would wear the display as often and in as wide a range of situations as possible, thus maximising the potential for the user to look at the display and re-centre when they are primed to take action. For example, while leaving the house to go to work a user might glance at their display (engagement), decide they're not being active enough (re-centring), and subsequently walk or cycle to work instead of driving (taking action).

Aside from allowing a user to better monitor their own level of physical activity, wearable ambient displays could also be effective at enabling users to support and persuade each other, either explicitly or implicitly. In Chick Clique (Toscos et al., 2006), and UbiFit Garden (Consolvo et al., 2008), the user's activity was shared with others, implicitly persuading them to be more active. The Pediluma wearable ambient display (Lim et al., 2011), on the other hand, attempted to draw the attention of others in proximity to the wearer. Observers' interest in the display would encourage the wearer to think about physical activity, constituting explicit social persuasion.

In Chick Clique and UbiFit Garden, activity information was shared through a mobile phone app, not an ambient display. Williams et al. (2006) and Kikin-Gil (2005) have explored explicit message passing via wearable ambient displays, although the messages were not about physical activity. In the Pediluma study, Lim et al. proposed the property of explicit social persuasion but were unable to demonstrate it in practice.

In my research I seek to explore this gap in the design space—the use of wearable ambient displays to make users aware of their own level of physical activity and that of others, such that this increased awareness might prompt the user to become more physically active (Bandura, 1991).

CHAPTER 3

Methodology

In Section 1.4, I outlined a number of unanswered questions around the use of wearable ambient displays to motivate increased physical activity. They covered three main categories: information presentation questions, which consider the way activity information is displayed, design questions, which consider properties of the device implementing the display, and motivation questions, which consider whether the device is effective at motivating people to engage with the information presented.

In this chapter, I describe the research methodology I employed to address those questions.

3.1 Design as Research

My research questions centred around wearable ambient display devices and display metaphors. In deciding on a specific methodology, therefore, I needed to consider whether suitable devices were available with which to implement a wearable ambient display. A suitable device would need:

- A display that would be persistently visible to the user, in order to allow the user to receive information at any time at a glance.

- A display that would be persistently visible to others, to enable explicit social persuasion by drawing their attention to the wearer (Lim et al., 2011).
- Ideally a colour display, so as to have greater visual appeal and be more attention-grabbing, in the style of Consolvo et al. (2008), and Lin et al. (2006).
- A sensor to detect physical activity and be wearable in a range of different situations.
- The ability to connect wirelessly to a network in order to upload the wearer's activity data and download group activity information.

Devices such as the various Fitbit models (Fitbit, 2014b) (Fitbit, 2014a) and the Nike+ FuelBand (Nike, 2014) had displays that only illuminated when a button was pressed, the device was tapped, or some other gesture was performed. Of those devices that did have a persistent display, such as the Samsung Gear Live (Samsung, 2014) (Figure 3.1), the display was monochrome or entered a monochrome "sleep mode".

The implications of using a commercially-available device were that the potential for the wearer or others to serendipitously receive information from the device's display would be limited. Any device that needed to be "woken up" to be viewed would impose the prerequisite that all interactions were deliberate, in contrast to the calm technology vision of Weiser and Brown (1996). The potential for explicit social persuasion, promoted by Lim et al. (2011), would also be limited. Similarly, devices that would generate a persistently visible monochrome display in sleep mode had dull displays that seemed little better than no display at all for the purposes of peripheral viewing.

Even if appropriate hardware were commercially available, at the time of undertaking this research no software existed to create physical activity displays on an embedded platform. I would have had to develop custom software and to have loaded it over the device's existing software, more than likely disassembling the device in

Figure 3.1: The Samsung Gear Live's display dims and becomes monochrome when inactive, limiting its usefulness as a platform to create an ambient display. (Phone Arena—John V.)

the process. This would have been a difficult undertaking without assistance from the hardware designer and/or manufacturer, which I felt was unlikely for practical and commercial reasons.

As no suitable device was available with which to create a wearable ambient display, I concluded I would need to construct a prototype myself. I therefore decided to employ a design-based research methodology where I would design, build, and evaluate novel physical activity display metaphors as well as the devices on which to implement them. Obrenović (2011) explains that this process of design and evaluation is itself a form of research. Domain theories, design frameworks, and design methodologies generated during the design process comprise generalisable knowledge that is applicable more broadly than to the single artefact for which they are created.

Design-based methodologies have been used extensively in similar research. For example, Consolvo et al. (2006), Consolvo et al. (2008), Lim et al. (2011) and Lin et al. (2006). Each proposed a set of theoretical underpinnings for their designs, proceeded to design and build devices and/or interfaces, tested them with real people in user studies and then evaluated the results to determine future directions. In the case of the two studies of Consolvo et al. it is clear in their published work over time how results from one design, prototype, and evaluate cycle fed back into the next cycle. For example, "UbiFit Garden" was an evolution of their previous "Houston" software. The domain theories and design frameworks generated by Consolvo et al. have significantly assisted and influenced the work of other researchers in the field of behaviour change in Human-Computer Interaction (HCI).

3.2 Evaluation Criteria

In order to evaluate specific display metaphor and device designs I needed to distil the high-level research questions above (Section 1.4) into a set of more concrete evaluation criteria. These criteria would map to the same categories as the research questions—information presentation, design, and motivation.

Information Presentation:

- Comprehension—Which properties of the device and displays affect user comprehension? (For example the display metaphor employed, the extent of the information presented and the way in which the metaphor functions.)
- Accuracy—Which properties of displays affect users' perceptions of the accuracy of the information presented? (This would be assessed qualitatively using questionnaires.)
- Explicit social persuasion—Which approaches successfully engage users in discussions with others about physical activity whilst respecting their privacy and relevant social norms? (A successful display would be one the user reports they are comfortable wearing in public or in social situations.)

Design:

- Size/Appearance—How does the size and appearance of the display device affect user acceptance?
- Ease of use—Which properties of the display device affect its practical use in real-world situations? (For example battery life, ease of charging and reliability.)

Motivation:

- Monitoring—How do we ensure that users notice the information presented and look at it regularly? (Measured qualitatively, based on user feedback.)
- Reflection—How do we encourage users to reflect on the information presented and discuss it with others? (Assesses the effectiveness of explicit social persuasion.)
- Engagement—In what ways do ambient displays encourage users to engage with monitoring their own physical activity? (Explores whether self-monitoring, and explicit and implicit social persuasion occurred, based on user feedback.)

3.2.1 Information Presentation

In evaluating an ambient display, a fundamental concern from an HCI standpoint is whether users of the display are able to comprehend the information in the way in which it is presented. Ambient displays by their nature are limited in the amount of information that can be conveyed peripherally; there is the need to display enough information to make the display useful whilst not overloading the user with too much information (thus reducing the ambient nature of the display) or presenting information in too cryptic a fashion (increasing the cognitive load to decode it).

Accuracy is another important criterion. Users should be able to translate the metaphor employed by the display into a sense of their own level of physical activity, and this sense should accord approximately with their own estimation of how active they are and with their actual activity level. Unlike a display employing exact measures, an ambient display need not (and cannot) represent the user's activity levels precisely. If it is too inaccurate, however, then the user may be prompted to act incorrectly on the basis of erroneous data, or they may lose trust in the display.

In the case of a display metaphor that presents the activity levels of others, accuracy extends to the way in which those activity levels are presented. If the intention is to enable implicit social persuasion—where users are motivated by seeing the progress of others—they need to receive information that is both accurate and that they perceive to be accurate. If the information is inaccurate, or the user believes that it is inaccurate, they may discount it and it may then fail to cause them to reflect on their own level of physical activity.

The final information presentation criterion relates to the way in which ambient displays could support explicit social persuasion, where users are prompted to think about physical activity when others engage them in a discussion upon seeing the display. Lim et al. (2011) proposed that the visibility of a display is important to attract attention and prompt these discussions. The obverse of the issue is that the user may not want others to see how active or inactive they are or there might be particular cultural or social environments in which an overt display would be inappropriate (for example, a business meeting or in church). It is important to strike the correct balance to enable explicit social persuasion whilst ensuring users will continue to wear the display device.

3.2.2 Design

The design and usability of the wearable display device itself directly affects whether users will wear it and subsequently monitor their own physical activity. An interface or device that is reliable, well implemented, easy to use, and suited to the target user population will meet with greater success than one that is unreliable, poorly designed, difficult to use, or inappropriate for the environments in which it is used.

The design of wearable technologies presents some unique challenges. There is an ongoing shift in the design of computer hardware from the functional to the aesthetic. Where previously users were willing to accept a beige metal box there is now the expectation, driven in particular by Apple but recently by all technology companies, that hardware will have outstanding visual appeal. This expectation is amplified when considering that wearable technology is intimately connected with the wearer's body, their sense of fashion and style, with how they view themselves and how they want to appear to others. If activity tracking wearables can connect with users' motivation to look good, we can maximise the likelihood that they will want to wear them and therefore that they will monitor their activity levels (Burns et al., 2012b).

Translated into practical design criteria, the display device should be comfortable to wear and accord with the user's existing wardrobe. The evaluation criteria of size and appearance then relate to users' perceptions of these properties. The device needs to be small enough, comfortable enough and attractive enough to gain user acceptance. These perceptions would be measured qualitatively using questionnaires and interviews. Balanced against this are the limitations of what is possible from an engineering standpoint, as well as what is practically achievable within the constraints of limited development time and resources.

Issues such as battery life, ease of charging, and reliability are also important. If the device has to be removed too often for charging, if charging is inconvenient, or if the device breaks down, then users may not wear it and the effectiveness of the intervention will be compromised. The operation of the device needs to be appropriate and acceptable for the real-world conditions in which users will wear it.

3.2.3 Motivation

The ability of self-monitoring interventions to change behaviour is premised on the principle that the act of monitoring is a precursor to behaviour change (Bandura, 1991). Monitoring requires not only that the user notices the information presented, but that they reflect on its meaning and engage in a process of continuing monitoring and of taking action on the basis of the information presented. In the context of wearable ambient displays this depends on the above criteria being met—that the display is comprehensible, accurate, visible yet respectful of the users' context, comfortable, and aesthetically pleasing.

The evaluation criteria proposed address each of these three aspects. Monitoring relates to whether users report noticing the ambient displays, although not whether they derived any meaning from it. Reflection relates to whether users engage in a process of considering the information presented. In the case of implicit social persuasion it relates to whether users consider the activity levels of others in the context of their own activity. With explicit social persuasion it relates to whether users are motivated to engage in discussions with others about physical activity. Finally, engagement relates to whether users commit to a long-term process of monitoring and reflecting, which would lead to reflecting being translated into action, resulting in behaviour change.

As the final Motivation research question (Section 1.4), I asked whether wearable ambient displays could create long-term behaviour change. Whilst this is an important question, Klasnja et al. (2011) argue that behaviour change is a poor variable to measure, in that it may reveal little of interest to HCI researchers in the context of short-term studies. Behaviour change, they explain, is a complex, long-term process, subject to frequent setbacks. Even if a short-term study were able to show that an intervention was able to change users' behaviour, that result would say little about exactly which elements of the intervention were effective.

Instead, Klasnja et al. (2011) suggest evaluating whether the putative active elements of the intervention are functioning. The focus can then be on the properties of these active elements which cause them to function effectively, which is a more relevant finding in the context of HCI research. In a self-monitoring intervention, the active elements are the provision of information and the monitoring of that information by the user. I therefore chose to focus on demonstrating the operation of these active elements, measuring the extent to which users monitored, reflected and engaged with the information, and determining which factors affected those behaviours.

These findings would then provide the foundations of a future iterative design process, where I would determine which wearable display device and activity display variants optimised user engagement. It would be possible to undertake a long-term study to determine whether this optimal design would result in actual behaviour change, and to what extent.

3.3 Evaluation Metrics, Methods and Instruments

In my research I measured the above evaluation criteria using various qualitative and quantitative instruments. I chose to measure comprehension, accuracy, and social persuasion using specific questions in questionnaires and semi-structured interviews. I presented questionnaire items as Likert items, for example "I felt the display accurately reflected my level of physical activity", with a five point scale from Strongly Disagree to Strongly Agree. I also used more broadly worded free-form response questions, for example "What did you like least and most about the device", to yield or confirm findings relating to these criteria. Particular questions in semi-structured interviews drew users' attention to these themes which they could then discuss in detail.

Similarly, I used questionnaire responses and semi-structured interviews to qualitatively measure users' responses to the size, appearance, and ease-of-use of wearable ambient display devices. I used empirical data collected by the devices themselves as part of a triangulation process to give additional weight to theories devised using qualitative methods. I programmed devices to record the times at which they were active and inactive, allowing the duration the devices were worn each day to be measured. This provides an indication of user acceptance—poor compliance with wearing the device might indicate it is uncomfortable, it is not functioning correctly, or the user is having trouble with it. If low wear time was indicated, users might be asked about aspects of the device they didn't like, in which circumstances they didn't or couldn't wear the device, or whether it functioned correctly.

I measured motivation through questionnaires and interview items that asked users to rate or discuss how they responded to the devices and metaphors used. A successful intervention would be one where users report that they noticed the device, thought about the information it displayed, and discussed that information with others.

In evaluating a technology intended to encourage people to change their day-to-day behaviour, the context of the person's usual lifestyle activities will be the most representative of the environment in which the intervention would ultimately be used. I argue, therefore, that real-world studies of these technologies should be preferred over lab-based studies when measuring aspects such as usability and motivation. This is also the approach most commonly used in evaluations of interventions in the existing HCI literature.

Despite the recommendation of Klasnja et al. (2011) to focus on the putative active elements of an intervention, it is nonetheless useful to collect and analyse direct and indirect measures of behaviour change. This may aid the interpretation of qualitative results relating to the final evaluation criterion—engagement. One direct measure, as previously mentioned, is actual physical activity as recorded by the wearable display devices. Indirect measures could include instruments to measure self-reported physical activity or instruments that measure psychological variables thought to be mediators for increased physical activity.

A widely-used self-report tool is the International Physical Activity Questionnaire (IPAQ), which asks participants to quantify the amount of time spent on a typical day undertaking various types of physical activity. The IPAQ is intended as a population surveillance tool, to measure the physical activity of a group of people as an aggregate, rather than to precisely measure the activity of an individual. Nonetheless, P. Lee, Macfarlane, Lam, and Stewart (2011) have shown that its proven test, re-test reliability means it can be used with care in repeated measures studies. Even if an increase in self-reported physical activity is not a reliable indicator of an actual increase, a perceived increase could provide evidence of monitoring and reflecting behaviours.

A promising psychological mediator variable is self-efficacy—an individual's belief in their own capacity to perform in certain situations (Bandura, 1991). Roesch, Norman, Villodas, Sallis, and Patrick (2010) showed that self-efficacy was an effective mediator variable for increased physical activity in a 12 month intervention. Whilst not showing a causal relationship between self-efficacy as a mediator and physical activity, this association suggests that self-efficacy could be a marker of future behaviour change. An increase in self-efficacy for exercise regulation, even in the absence of a measured increase in actual physical activity over the short-term, could be indicative of psychological change supporting increased engagement in physical activity in the long-term (ideally after the user has stopped the intervention). This measure could be stable against short-term variability in users' physical activity levels.

In summary, I employed a methodology consisting of a combination of these techniques and instruments. I used Likert and free-form questionnaire items, and semi-structured interview questions, to measure users' responses to each of the information presentation, design, and motivation evaluation criteria. Additionally, I used empirical data from the devices, such as wear time, to provide an additional indication of ease-of-use and monitoring behaviour. Lastly, I used measures of actual physical activity, self-report physical activity and a psychological mediator to aid

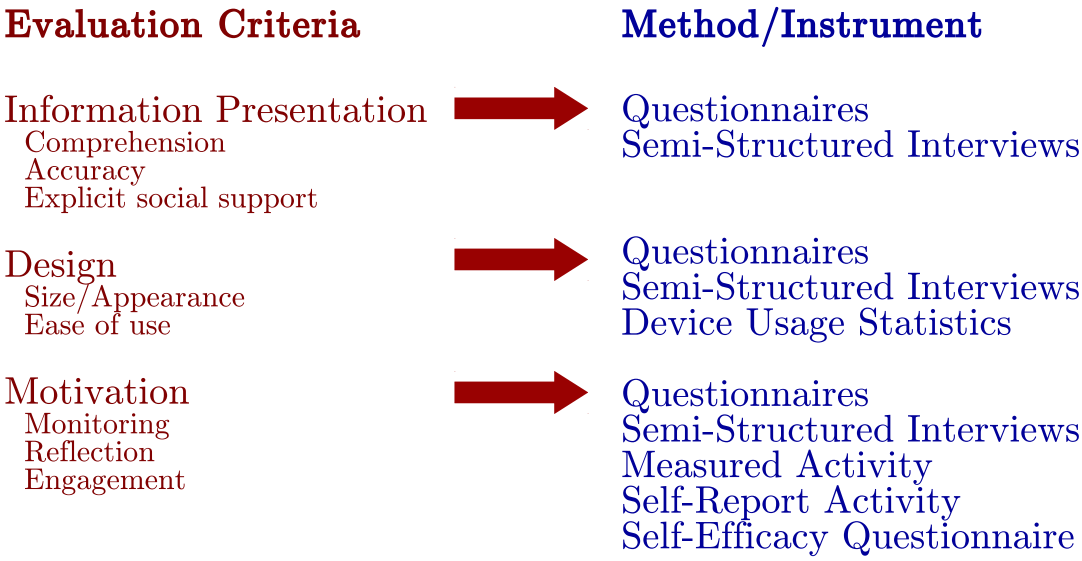


Figure 3.2: Mapping of evaluation criteria to evaluation methods/instruments

interpretation of the qualitative data.

My design process, whilst not being an iterative design process in the strictest sense, nonetheless had an iterative characteristic. I began by rapidly developing a low-fidelity display device prototype and display metaphors and tested these with a small cohort of users. I then proceeded to develop a refined device and metaphors and then evaluated these in a more rigorous user study.

Chapter 4

Design and Evaluation

In this chapter I describe two wearable ambient display devices, "Activmon" and "Activthings", each implementing an individual and group activity display. I discuss the design and results of a short scoping study, where I evaluated the first device and activity displays. I then proceed to describe the design of the second device and activity displays, informed by the results of the scoping study. Finally, I introduce a larger study to evaluate the second device and activity displays, the results of which I discuss in Chapter 5.

4.1 "Activmon"

4.1.1 Design Questions

I began by translating the high-level research questions from the *Information Presentation* and *Design* categories (Section 1.4) into a series of low-level design questions, the answers to which would guide my design process.

Information Presentation:

- Which data should be presented to the user?
- Which ambient delivery mechanism should be used?
- Which metaphor/coding should be used?

Form:

- Where should the display be located on the user's body?
- What form should the display take - in terms of size, shape and appearance?

The intention of the *Information Presentation* design questions was to answer the research questions relating to comprehension, perceived accuracy and respect for users' privacy. The intention of the *Form* design questions was to answer the research questions relating to acceptance, user satisfaction and ease-of-use.

Which data should be presented to the user?

Existing commercial wearable devices, discussed in Chapter 2, attempt to provide users with as many data as possible—steps taken, flights of stairs climbed, distance travelled, heart rate, body heat, or perspiration. However, research is yet to convincingly demonstrate that the depth or breadth of data provided is in any way associated with user acceptance of or satisfaction with a device or display.

Ambient display designers are forced to be judicious in this regard. A single ambient display employing a simple metaphor can convey less raw data to the user than a screen filled with numbers, graphs, and text. Mankoff et al. (2003) highlight this tradeoff, noting that ambient displays should convey "just enough" information to be useful, but not so much that the display becomes cramped.

In the context of physical activity monitoring, the smallest quantum of useful information would be "do I need to be more active?" The datum in this case might be how active the user has been as compared to their average activity (more or less active than usual), or an ideal goal (such as the Australian Government *Physical Activity Guidelines for Adults* (Department of Health, 2005)). From just this information the user is able to understand how they should rate their recent activity, and also whether they need to make an effort to increase their activity.

This is not to say that the user shouldn't have access to additional data if they so desire—these can still be made accessible through a more traditional screen-based interface on a device such as a PC or smartphone. The distinction between this approach and existing activity monitors is that the wearable ambient display is intended to be useful when used in isolation—users need not consult any additional data to obtain a benefit from the device, although they may if they wish. In contrast, existing wearable activity monitors are designed to collect data that will be fed into high-complexity, high-engagement displays, and to act as a reminder for the user to engage with those displays.

I argued in Section 2.4 that wearable ambient displays could seek to support both implicit and explicit social persuasion, by presenting information to the wearer about others' activity and drawing others' attention to the wearer's display. In terms of presenting others' activity, the smallest quantum of useful information would be "are other people being active?". The information presented could be a simple binary indication of the activity of others—the indication would be present when other wearers were active and absent when they weren't.

Which ambient delivery mechanism should be used?

An ambient display could present data using any ambient means that communicates with any of the five human senses (sight, hearing, touch, smell, and taste). All of the ambient displays discussed previously have used light and colour to convey data via sight. Touch interfaces are possible—heating and cooling of a person's skin and different patterns of vibrations have been used to convey data in an ambient fashion

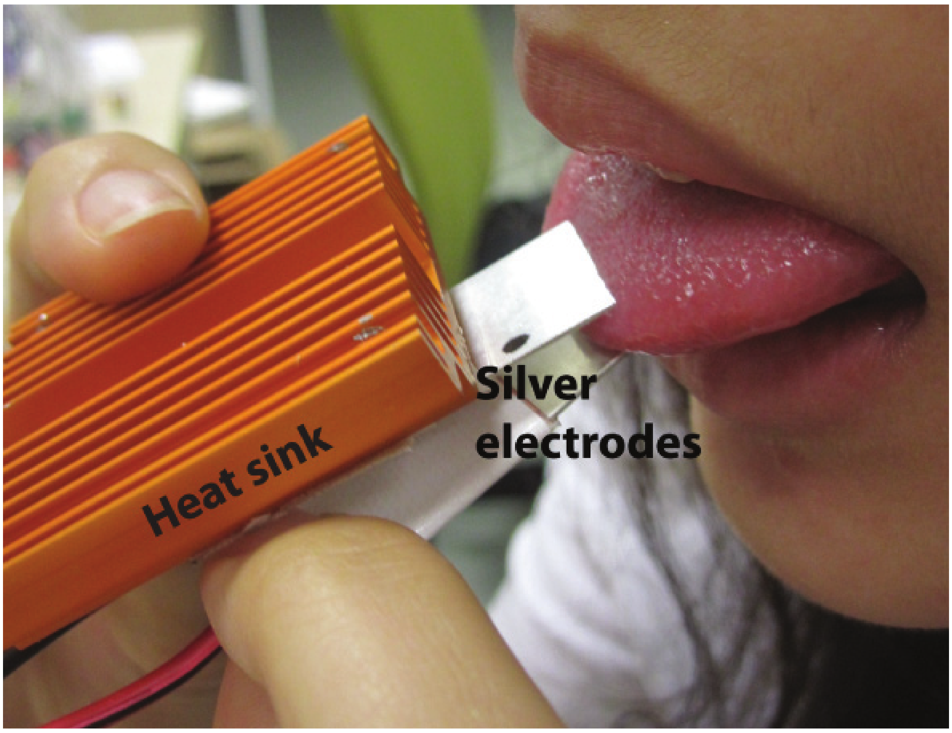


Figure 4.1: Electrical stimulation of the tongue can create taste sensations (Ranasinghe et al., 2012)

(W. Lee & Lim, 2010) (Saket, Prasojo, Huang, & Zhao, 2013). Hearing, smell, and taste have also been explored—computer-activated scent bottles can be used to stimulate smell (Kaye, 2004), and electrical stimulation of the tongue can be used to create different tastes (Ranasinghe et al., 2012) (Figure 4.1)

A visual display remains the most practical and least intrusive option given typical social norms. Smell and taste require complicated hardware that would be difficult to build into a device that could be worn long-term, and would be more likely to result in awkward rather than positive interactions with others when worn in public. Hearing and touch are more practical but could also be intrusive. A device that constantly produces noise might irritate the user and be inappropriate in a wide range of social and cultural contexts. A device that vibrates would tend to prompt immediate re-centring on the device, making for an ineffective ambient data delivery mechanism.

Figure 4.2: Gear Live with a colour LCD display (SAMSUNG)

A device that lights up with a persistent visual display might still be seen as intrusive and inappropriate in certain contexts, but is simpler to construct, can be miniaturised for long-term wear, best meets the definition of "Calm Computing" (Weiser & Brown, 1996), and is similar to other interfaces users are already likely to have had experience with.

The way in which light and colour are employed is key to creating an eye-catching visual display. Two possible options are a colour LCD (as used for example in the Samsung Gear Live, Figure 4.2) or discrete LEDs (as used for example in the Nike+ FuelBand). I decided to follow the example of Pediluma (Lim et al., 2011) and use discrete LEDs due to their superior vibrancy, daylight visibility, lower cost, and ease of use in the prototyping process. Discrete LEDs align well with the requirements of an ambient display: presenting a small number of data in a prominent way to aid glanceability.

The device should present a persistent visual display, to enable the wearer to glance at it at any time and to prompt conversations with others (explicit social persuasion, as defined in Section 2.4). This requirement needs to be balanced against battery capacity, which will be limited by the competing requirement to make the device as small and lightweight as possible.

Which metaphor/coding should be used?

Having decided to use a discrete LED display, I needed to devise a simple and intuitive way to represent individual and group activity data using such a display. Fish'n'Steps (Lin et al., 2006) and UbiFit Garden (Consolvo et al., 2008) both employ simple metaphors to convey physical activity data. In the case of Fish'n'Steps, the condition of one's fish maps to physical activity—the size and facial expression are easy to gauge quickly, and it is easy to understand whether a particular condition is good or bad because they map to real life concepts that people already understand as good or bad. In UbiFit Garden, the state of one's garden reflects physical activity: again, something that can be assessed and understood at a glance.

A metaphor suitable for a discrete LED display needs to be simpler but still comprehensible (Mankoff et al., 2003). Two popular metaphors that have been used in the past are the progress bar metaphor and the traffic light metaphor. The progress bar metaphor involves representing a single variable using a number of discrete LEDs which light in sequence to show where that variable is within a range. Position rather than colour is significant in such a display. In the context of the physical activity ambient display, few or no LEDs active would mean 'you have not done enough physical activity', and all LEDs active would mean 'you have done enough physical activity', with the number of LEDs active compared to the total number of LEDs representing the amount of progress towards the final goal.

The progress bar metaphor has been used in existing wearable activity monitors, for example the Nike+ FuelBand (Nike, 2014) and the Fitbit Flex (Fitbit, 2014a) (Figure 4.3). In both of these cases the metaphor is not intended to be an ambient

Figure 4.3: Fitbit Flex with a status bar display created using discrete single-colour LEDs (Fitbit)

display—it is only activated for a short period of time when the user presses a button. Rather than answering the question “how active should I be?”, the display is primarily intended to provide a brief summary of high-complexity information that the user would view on their smartphone.

The traffic light metaphor involves representing a single variable using colours commonly associated with traffic lights and which have well-understood meanings—red means stop/low/negative/bad, green means go/high/positive/good, and yellow is somewhere in between. The colours can be discrete or on a colour spectrum from red to green. In one possible mapping to physical activity, red would mean ‘you have not done enough physical activity’ and green would mean ‘you have done enough physical activity’, while yellow and shades in between the extremes of red and green would acknowledge some activity done but indicate that more is needed.

An arguable drawback is that the use of red to represent ‘do more’, in this context, is the inverse of the meaning of a red traffic light, ‘stop’. The colour red has previously been used to represent ‘bad’ in health contexts, however, with a notable example being front-of-pack labelling for food (Sacks, Rayner, & Swinburn, 2009).

Figure 4.4: Ambient Energy Orb with a traffic light display created using a multi-colour LED (Ambient)

Of these two options the traffic light metaphor is more popular with ambient displays, having been used for example in the Ambient Energy Orb to represent time-of-day power pricing (Ambient Devices, 2014) (Figure 4.4), and in the Waterbot tap to show water temperature (Arroyo, Bonanni, & Selker, 2005). The traffic light metaphor is also more visually appealing as part of an ambient display as it makes better use of colour.

I therefore decided to use the traffic light metaphor, expressing physical activity on a scale and mapping this scale onto a colour spectrum. The zero point of the scale would represent no physical activity, and the other end would represent a physical activity goal.

In common with pedometers and other existing activity monitors, I chose to visualise the wearer's activity over the course of a day. At the beginning of the day the light would be red, representing no physical activity that day. During the day, as the wearer was active, the light would change toward yellow. Eventually the light would turn green as the wearer approached their goal, and turn to a terminal colour—blue—as the goal was finally reached. The terminal colour introduces an additional complexity to the traffic light metaphor, however without it the subtle shift from near-green to fully green would be insufficiently obvious to show goal achievement.

I needed to address the issue of selecting activity goals for users. Consolvo et al. (2009) discussed a number of approaches in the existing literature.

- Self-set: The individual sets their own goal.
- Assigned: Goals are assigned by a fitness or medical expert, or created based on national physical activity recommendations.
- Participatory: The individual works with a fitness or medical expert to set their goal.
- Guided: A fitness or medical expert designs multiple goal options from which the individual may choose.
- Group-set: The individual works with a group of people they know, or strangers, to set a goal for the performance of the group as a whole.

The accompanying field study of Consolvo et al. (2009) involved an ambient display implemented on a mobile phone. Self-set, participatory and guided goal-setting strategies, in this case, could be implemented using a graphical user interface on the phone. I felt that these strategies, however, would be difficult to implement using a wearable ambient display. A simple device, for example using coloured LEDs, is optimised for output and is poorly suited to input of data, especially those involving numbers. My decision to use a unitless measure of activity (see Section 4.1.3) would have made it difficult for users to create meaningful goals using familiar units. Whilst I could have provided an accompanying smartphone or web app to allow goal setting, I felt this was outside the scope of my research (focussing on ambient displays).

I chose instead to employ assigned goals. Mankoff et al. (2003) stress that ambient displays should add minimal cognitive load, and I have argued previously that it is important to reduce or remove barriers to engagement with persuasive technologies (Section 2.4) (Burns et al., 2013). I was concerned that forcing all users to select their own goals would be counter to these principles, and would discourage less engaged users.

Unlike the assigned goals described by Consolvo et al. (2009), based on medical guidelines, I created goals for users based on their own past performance. I decided to monitor each user for seven days, determine an average of the days' activity, and then set the activity goal to be ten percent above that average. I then re-calculated the goal every week thereafter, to adjust for an increase in activity over time. This addressed one of the criticisms of assigned goals—that they are arbitrary and impersonal.

Having considered colour as a way of conveying individual activity information, I needed a second metaphor that could be displayed on this same interface to convey information about the activity of others. Pulsation of light is something that has previously been used in other wearable ambient social notification systems (Williams et al. (2006)). I felt that this would add a second prominent visual element that would be peripherally noticeable and give a sense of excitement, but without being too intrusive.

Imagining that users in a group might each have their own linked devices, when one user was exercising the lights on the other users' devices could flash to make them aware of this. The speed of the pulsing could increase depending on the intensity of physical activity of those in the group. This group display could serve to increase a wearer's motivation by allowing them to observe others' successes (in this case, increasing their activity levels) vicariously, and serve as a form of subtle persuasion on behalf of active users to get sedentary users to be active as well.

Where should the display be located on the user's body?

In deciding where on a user's body to position an ambient display, I considered whether particular locations would be comfortable, convenient, allow the display to be easily viewed and allow accurate activity sensing. Existing wearable devices have used the wrist (Fitbit, 2014a), the upper arm (BodyMedia, 2014), the waist (Consolvo et al., 2006), and the foot (Lim et al., 2011).

Fujiki et al. (2009) found that a location close to the user's centre of mass, such as the waist, gave accelerometer readings that correlated well to actual energy expenditure (for walking and running). Consolvo et al. (2006) found, however, that this location was particularly inconvenient for women, as some women's clothing (such as dresses) lacked a convenient location to which a device could be attached.

BodyMedia's "Fit" device attaches to the user's upper arm, a location which they argue is a compromise between comfort and accuracy (BodyMedia, 2014). It is nevertheless an unusual location in which to wear something. Similarly, Lim et al. (2011) tried attaching an activity monitor and ambient display to the user's foot, but reported that users felt this was an unusual or awkward location in which to wear a device.

Harrison, Lim, Shick, and Hudson (2009) showed that the location of a wearable display affected users' ability to see and respond to the information presented. They placed flashing indicators on different areas of users' bodies and measured the length of time it took the user to notice the indicator. They found the wrist was the best location, closely followed by the upper arm. When the indicator was placed on the user's foot it took a long time to notice, and sometimes the user didn't notice it at all.

The wrist therefore seems to be a good compromise. It is a location where users will be able to see and respond to information that is presented, it is a natural place for users to wear something and it is not a position where the device would need to attach to clothing. The relationship between accelerometer readings and physical activity is not as good as for the waist, but it is still acceptable (Fujiki et al., 2009).

What form should the display take - in terms of size, shape and appearance?

I argued previously (Section 3.2.2) that an important high-level design consideration is ensuring the display is congruent with the user's existing wardrobe, the way they see themselves, and the way in which others view them. Many people would wear, or would have worn, watches, bracelets, or wristbands, making the wrist a natural location for a wearable display. This is the current thinking in the commercial realm, where almost all exercise trackers on the market are intended to be worn on the wrist. Manufacturers appear to be moving away from devices based around other locations (the waist in the case of the original Fitbit and the upper arm in the case of BodyMedia FIT (Figure 4.5)). As for the foot, the experience of Lim et al. (2011) was that users found this location unusual or uncomfortable.

In response to user preferences, the bracelet form factor is being constantly reimagined. The trend is to devices that are lighter, smaller, and thinner and therefore more comfortable and discreet. In the case of an activity monitoring bracelet, it needs to be comfortable enough for all-day wear and use during exercise activities. Ideally it would be waterproof, although this adds significant time, expense and complexity to the design and construction process and therefore may not be a practical goal for an initial prototype.

4.1.2 Hardware Design

Having explored these design considerations, I proceeded to define the hardware requirements for the Activmon wearable ambient display.

I decided that, at a minimum, the device would need to have:

Figure 4.5: The BodyMedia FIT is worn on the upper arm—an unusual location (BodyMedia)

- An accelerometer to track the wearer's physical activity.
- A multi-colour LED to create the ambient display.
- A wireless radio to upload activity data to a central server and download activity data regarding other users, to enable calculation of the individual activity display and group activity display.

I used an existing wearable prototype circuit board I had built with these capabilities, although without the intention of using it specifically as a physical activity tracker. It incorporated a PIC microcontroller, an RGB LED, three-axis accelerometer, and a Bluetooth radio. It was powered by a 450mAh rechargeable battery, providing one day (about 16–18 hours) of power. The battery was charged by connecting a USB charger to a mini-USB socket on the board.

For the purposes of this scoping study, the primary goal was to test the various ambient displays and the display device itself. Appearance was a secondary concern.

Figure 4.6: Activmon Prototype

For this reason, I developed a simple casing for the board and battery consisting of a rectangular plastic cut-out that could be folded around the electronic components and sealed with tape. Holes in the cut-out allowed access to the power switch and charging socket. This plastic "sandwich" could then be inserted into a silicone wrist-band designed to hold an iPod nano. The band secured the device to the user's wrist, with the elasticity of the silicone ensuring a secure fit for a variety of wrist sizes. (Figure 4.6)

4.1.3 Software Design

I developed a distributed software architecture, where processing could be split between the wearable devices and a central server (Figure 4.7). The processing power and storage capabilities of a device such as the Activmon prototype are limited, so it is necessary for many calculations to be relegated to the central server to ensure adequate speed and reliability. This was also the best way to enable synchronised group activity displays to be delivered to each user.

Each device would continually record the wearer's physical activity and report the collected data periodically to the server. After accumulating enough data, the server would create a goal for each user. These goals would be fed back to the devices, where they would be used to create an individual activity display. The server would also create a group activity metric which would be provided to all wearable devices to invoke the group activity notification whenever necessary.

It was impractical for the Activmon devices to connect to the Internet directly. Rather, the device would connect to the wearer's mobile phone, via a Bluetooth connection, and through the phone to the Internet.

Accelerometer Conversion

I needed to decide on the manner in which accelerometer readings would be converted to a physical activity display. Existing wearable activity monitors employ one of two main approaches. The first is to apply some minimal filtering to the acceleration signals and then use the magnitude of the resulting acceleration vector to construct a unitless quantity. This is the approach taken by Nike with the Nike+ FuelBand—accelerations are turned into a quantity called "Nike Fuel" (Nike, 2014). The second approach is to use classifier algorithms to process the raw acceleration data into a high-level measure of physical activity. These attempt to guess the activity undertaken and apply standardised energy expenditure models, such as calories burned or steps taken.

The unitless quantity approach is conceptually simple and straightforward to implement. It requires a minimum of post-processing and yields a number that is moderately to highly correlated with energy expenditure. By applying thresholds to the rate of change of this number, it is possible to determine if activity is of light, moderate or vigorous intensity, with fair to excellent accuracy (Rowlands, 2009). This number, however, cannot be directly related to any of the more familiar units of steps, calories or kilometres, and therefore it will not be comparable between different measuring devices.

The activity classifier approach is more complicated to implement, relying on al-

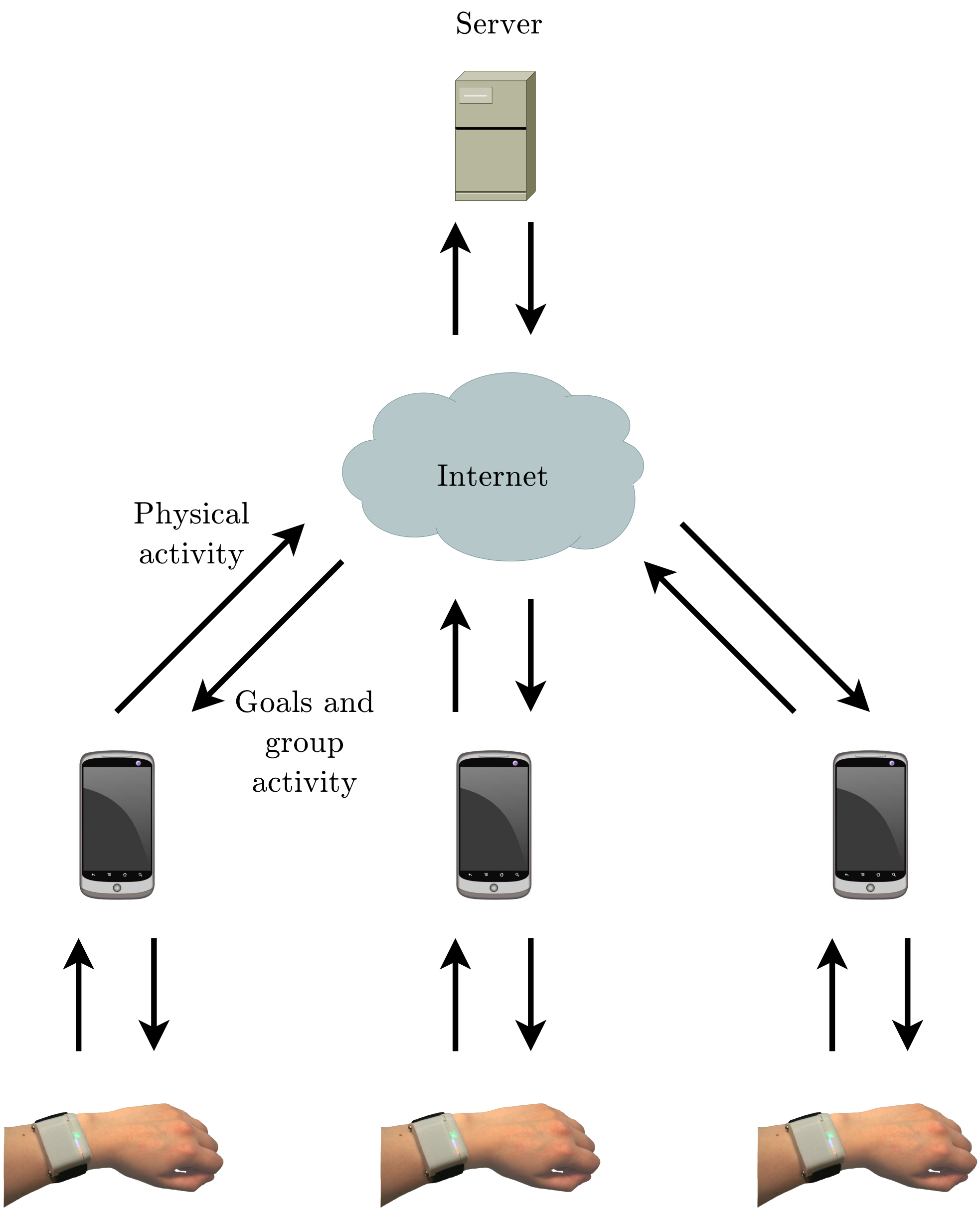


Figure 4.7: Activmon System Architecture

gorithms that need to be carefully calibrated, ideally against some ground truth measurement. The validity of the results are significantly impacted by the type of classification model used, and the quality of the classification data set. Lockhart and Weiss (2014) found that, of the 34 published activity classifier papers they reviewed, many used limited data sets which negatively impacted the validity of the results obtained. These results, however, are in familiar units and can be compared between measuring devices.

I chose to employ the unitless quantity approach. The objective of the ambient display was to provide the user with an impression of the need for more physical activity, rather than precise quantities. It was not necessary, therefore, to create a representation in actual units (such as steps, calories or kilometres). I was also concerned about the need, if I were to use a classifier algorithm, to limit detection to certain types of traditional exercise activities such as walking and running. I considered that overall physical activity, no matter what the form and the intensity, was important. For a very sedentary person, simply walking a short distance at a moderate pace, or doing some cleaning around the house, is significant, and there is evidence this non-exercise activity thermogenesis (NEAT) is important in helping to prevent obesity (Levine, 2002). Further, complex algorithms would have been difficult to implement on the low-power, low-energy processors I intended to use.

In order to obtain acceleration data, I sampled the three axis accelerometer's y and z axes at a rate of approximately 100 Hz (it was not possible to sample the x axis due to limitations of the Activmon device). This gave a maximum detectable frequency of $\leq$ 50Hz (Nyquist, 1924). Bouten, Koekkoek, Verduin, Kodde, and Janssen (1997) have shown human motion consists of acceleration components with frequencies well below this threshold, and this frequency is consistent with existing approaches (Lockhart & Weiss, 2014).

I then processed the raw acceleration data using a primitive filtering algorithm. I summed acceleration readings in the y and z axes to create variables σ_n, subtracted each σ_n from the previous sum σ_{n-1} to create a difference d_n, and added the magnitude of this value to a counter c, if d_n was greater than an adjustable threshold ϵ.

$$\sigma_n = y_n + z_n \tag{4.1}$$

$$d_n = |\sigma_n - \sigma_{n-1}| \tag{4.2}$$

$$c = \sum_{d>\epsilon} d_i \tag{4.3}$$

This simple approach had a number of important limitations as a pure indicator of physical activity levels. As mentioned, due to hardware restrictions I was only able to measure acceleration in two axes. The axis that was not measured was oriented along the length of the wearer's arm (see Figure 4.8) and therefore was less significant than the other two, but acceleration components were lost nonetheless. Further, the approach of summing acceleration components was simple to implement in software but did not accurately compute the magnitude of the acceleration vector. The magnitude of any acceleration between 90 degree offsets on the plane would be over-stated. Additionally, a positive-going transition in one axis could potentially be cancelled out by a negative-going transition in another axis, causing both components to be filtered out. This didn't invalidate the algorithm as a rough proxy for physical activity, as in practice there was still a difference, in average magnitudes of d_n over time, between sedentary and physical activities, maintaining the perception of accuracy.

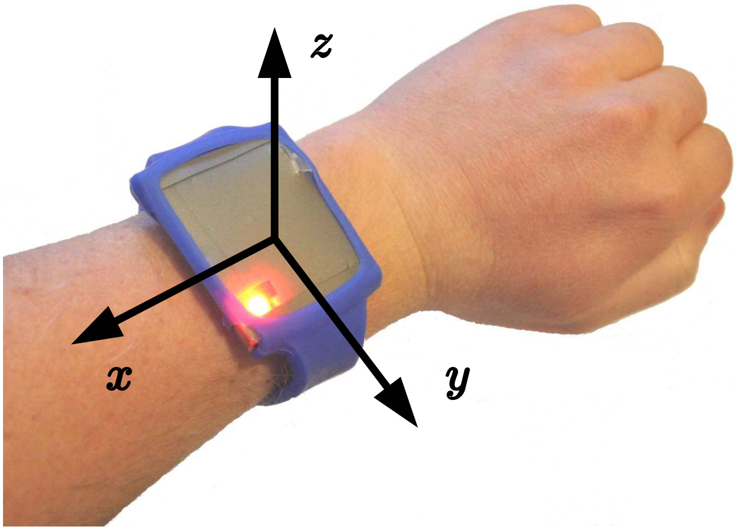


Figure 4.8: Orientation of accelerometer axes in relation to Activmon as worn

Individual Display

The individual activity display would show the user their current level of activity for a day, relative to an activity goal, using a red-to-green "traffic light" display. Given the aim of reducing prerequisites to user engagement, I decided to calculate these goals automatically for each user. Another consideration was that the unitless nature of the underlying physical activity representation would have made it difficult for users to set their own meaningful goals, as there was no analogue with steps and calories.

In order to calculate each goal I chose a strategy of averaging the maximum counter values for a user for each day of the first week of wear, c_1 to c_7, and adding a fixed percentage to this average. This would have the effect of giving the user a goal for the following week slightly above their ordinary level of daily activity for the first week. At the beginning of the second week, the wearable device would display a colour on a spectrum from red to green depending on the current activity counter value with respect to the goal, thus creating the traffic light metaphor previously discussed. The goal could be re-calculated in this fashion for subsequent weeks.

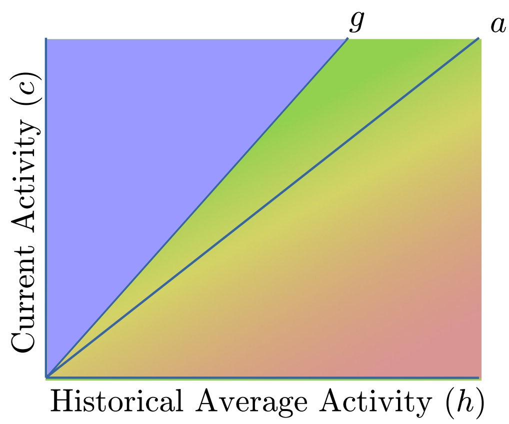


Figure 4.9: The day-by-day activity display where c resets every day

Figure 4.9 shows how a user's individual activity display would change depending on the user's historical average activity, h, their current activity level, c, and their daily goal, g. At the beginning of each day c would be reset to zero, resulting in a red display. As the user's current activity level c increased toward their goal g (created as above from h), their light would change from red through yellow to green. Reaching the goal line g would cause the light to turn blue to indicate the goal had been reached (as opposed to showing a persistent green indication).

In practice I created the individual activity colour using the device's RGB LED. The RGB LED had three discrete elements—red, green and blue—that could be set separately to create a specific colour from the mix of primary colours. Using a pulse-width modulation (PWM) algorithm, I was able to vary the apparent brightness of each of these segments in order to create a range of colours. In particular, by varying the red and green elements I was able to create a colour on a spectrum from red to green. For example, red and green combined at equal brightnesses would create yellow (indicating a value in the middle of a scale). Green set to a brightness greater than that of red would create a greenish-yellow (indicating a value higher than the middle on the scale).

Whilst the PWM algorithm was capable of producing up to 64 gradations of brightness for each RGB LED element, in practice the number of noticeable gradations was lower and the high brightness settings proved to be too bright. After experimenting with various brightness levels, I decided that the 12 lowest brightness levels (in addition to "off") were suitable.

I implemented an algorithm to set the brightness of the red and green elements as follows. First, I created a goal based on the past week's activity levels:

$$a = \frac{1}{n}\sum_{i=1}^{n} a_j \tag{4.4}$$

I created an intermediate value s:

$$s = \frac{c}{(\frac{g}{steps})} \tag{4.5}$$

where g was the current daily activity goal, c was the current value of the daily activity counter and *steps* was the number of coloured light gradations (12). I then rounded s to the nearest whole number. I used s to set the brightness of the green element and its inverse to set the red element. When s was greater than or equal to 12 (the user had achieved their goal) I disabled the red and green elements and set the blue element to maximum brightness.

Group Display

The group activity display would allow users to monitor the activity of others by pulsing a light when one or more other wearers were active. To create this display I needed to determine when a user was active and when they were sedentary. Ideally I needed a mechanism that would tell the two apart without the need to manually take a baseline measurement for each type of behaviour for each user. I assumed that, for most users, a typical day would consist mainly of sedentary activity interspersed with some physical activity. Given this pattern of behaviour, I proposed calculating a long-term average of activity rates for a user and treating outliers in this long-term average as indicative of physical activity.

The implementation was as follows. Every 15 minutes each device sent its current activity counter value c to the server. The server calculated a derivative of the counter c with respect to time t as:

$$a_i = \frac{c_i - c_{i-1}}{t_i - t_{i-1}} \tag{4.6}$$

where $c_i - c_{i-1}$ represented the difference in activity counter values between the current value of the activity counter and the previously reported value (or zero if there was no previously reported value for the current day). $t_i - t_{i-1}$ represented the difference in time between the current report and the previous report (or the current time less the time of log-in if there was no previous report). t was expressed as fractional hours (e.g. 0.5 represented thirty minutes).

The resultant value a_i represented the rate of change of the activity counter in "counts per hour". A higher value of a_i represented a higher rate of physical activity over the past (i'th) reporting period, and a lower value of a_i represented a lower rate of activity. For example, assume we have two activity counter readings: the first (v_{i-1}), a reading of 1000, and the second (v_i), a reading of 1500. Assume also the readings were taken 15 minutes apart, so $t_i - t_{i-1} = 0.25$ hours. We would calculate a_i as follows:

$$a_i = 1500 - \frac{1000}{0.25} \tag{4.7}$$

The server then calculated a sliding window average avg_i of the most recent n rates of activity a_i over a period of 8 hours ($N = 30$) as follows:

$$avg_i = \frac{1}{n} \sum_{j=i-n+1}^{i} a_j \tag{4.8}$$

The server then calculated a value d_i by dividing the most recent activity rate a_i by the user's most recent sliding window average avg_i:

$$d_i = \frac{a_i}{avg_i} \tag{4.9}$$

If d_i was greater than one, the user had engaged in an increased amount of physical activity over the most recent reporting period as compared to the sliding window average for the previous 30 periods. Otherwise, the user had engaged in a decreased amount of physical activity.

The server subsequently calculated the average of the most recent d_i values for m number of users in the group:

$$d_{groupavg} = \frac{1}{m} \sum_{k=1}^{m} d_{ik} \tag{4.10}$$

The server subtracted $d_{groupavg}$ from 10 and clamped the resulting value to the range $[0, 10]$ to create a value d_{inverted}. If one or more users in the group, excepting the current user, had a d_i greater than or equal to three (the activity threshold—see Appendix Section B.1) d_{inverted} was returned to the user's device. The device's RGB LED would then pulse five times, pause and then repeat. The pause between pulses was determined by d_{inverted}. A lower value (representing greater group activity) would cause more frequent pulsing, while a higher value (representing lesser group activity) would cause less frequent pulsing. I judged that, in order that the group indication not be annoying, pulsing should be limited to a five minute period after each 15 minute update. Clamping the value d_{inverted} also ensured a sensible maximum and minimum pause between each flash in a set of five.

If no users in the group (apart from the current user) had a d_i above the activity threshold, then the user would receive a d_{inverted} value of zero and would not receive a flashing indication. Because the user currently requesting d_{inverted} from the server was excluded from the calculation, a user would never receive a flashing notification if they were the only person in the group being active. Further, values of d_i for other users that were greater than 30 minutes old were not included in the calculation, such that only the recent activity of others would result in a flashing notification.

Ideally the connection between each user's device and the server would be persistent, such that if any one wearer did physical activity this would be communicated immediately to the other devices. In practice, however, this would drain the battery of Activmon and its connected phone too quickly. I decided an acceptable compromise would be to have Activmon connect to the server once every 15 minutes. Group activity updates would be delayed ("near-realtime"), but this would only be noticeable if a wearer happened to be physically active whilst in the company of another wearer. In practice, the display could still perform the function of notifying its wearer *how* active other users were without needing to provide completely realtime updates.

The choice of update frequency, however, had an impact on the device's ability to recognise periods of physical activity. Too long of a window would mean that short bursts of activity would be under-represented. I decided in this case that a 15 minute window was sufficient, as significant physical activity should last ten or more minutes (Department of Health, 2005) and this would cause a recognisable change in a_i.

Before deploying this software in a user study, it was important to determine whether its component algorithms functioned as intended in practice. I describe the validation process in Appendix Section B.1).

I published this design as "Activmon: A Wearable Ambient Activity Display" in proceedings of MMS 2011, Lecture Notes in Informatics (Burns et al., 2011).

4.1.4 Pilot Evaluation

An important consideration for wearable ambient displays is to understand the usability issues that would lead users to wear or not wear the display. For the display device to effectively convey information in an ambient fashion, users need to wear it for a not insignificant amount of time each day and regularly throughout the week. Wearable technology faces unique challenges—being more closely aligned with the body and intimately connected to a person's sense of self, it has a higher standard to reach in terms of style and comfort than a laptop or desktop PC.

The Activmon device was a low-fidelity prototype and not particularly comfortable or stylish. Nonetheless I decided it was important to undertake an evaluation of the device and its activity displays in order to better understand the usability factors that would affect real-world user engagement. With this knowledge I would then re-design the device with these factors in mind.

I recruited five colleagues from the School of Computing and Information Systems at the University of Tasmania, and provided them each with an Activmon device to wear for two weeks (there were five Activmon devices in total, and all five participants wore the devices simultaneously). In the first week they received no feedback—Activmon monitored their physical activity but showed no lights. In the second week, each user received the red-yellow-green light indication with a daily goal[1] of 5% higher than their first week's average activity.

For the purposes of the flashing group activity indication, I allocated all five users to the same group. As with the individual activity indication, each user received no display for the first week. In the second week each user's RGB LED pulsed when at least one other member of the group was physically active. The intensity of pulsing varied depending on the number of people in the group who were active and how active they were.

[1]Given the short length of the study I actually set each user's goal manually rather than writing software to do this.

To allow the Activmon devices to connect to the server, I gave each participant an identical pre-paid mobile phone and asked them to carry it with them at all times. I instructed them to wear the Activmon device on either wrist during their waking hours, to charge it every night, and to charge the mobile phone every few days or whenever the battery indicator showed low power.

Post-study I employed a combination of qualitative and quantitative measures (Section 3.3), each addressing one or more evaluation criteria (Section 3.2). In terms of quantitative measures, I analysed the activity counter data returned by each device and stored on the server. In terms of qualitative measures, I asked each participant to complete a short online questionnaire, consisting of a series of statements each with a five point Likert scale. The statements covered usability, comprehension and perceptions, and were both positively and negatively keyed. I also asked each participant to take part in a semi-structured interview. All five users completed the two week study. All five participated in an interview and four responded to the online questionnaire.

I published the results of this evaluation as "ActivMON: Encouraging Physical Activity Through Ambient Social Awareness", in CHI '12 Extended Abstracts on Human Factors in Computing Systems (Burns et al., 2012a).

I have provided copies of the information sheet and consent form provided to participants, as well as the questionnaire items, in Appendix Section D.1.

4.1.5 Information Presentation

Comprehension

It was important that users be able to comprehend the information presented through both the individual and group displays. I had explained the operation of both displays to them before the study. For the individual display, that a red light meant no activity at the start of a day, green meant they were close to their goal and blue meant they had achieved it. For the group display, that flashing indicated that others in the group were being active.

All users completing the questionnaire ($N = 4$) responded in the negative to the statement "I had trouble understanding the colour". In hindsight this was an ambiguous question as it could refer either to comprehension of the red-to-green display in general or comprehension of the colour-to-activity mapping. From discussions with participants in interviews, however, it was clear that the traffic light mapping was well understood—"red is bad, green is good."

Users were split on the question of "I wanted to see a graph of my progress", with two agreeing and two answering "neutral". Only one participant, a regular user of mobile phone self-tracking apps, expressed a strong desire for numbers and graphs over an ambient display alone.

It was promising that participants, for the most part, did not express a strong preference for numbers, graphs and historical trends over the ambient display provided. Whilst there was no reason that information couldn't have been provided in addition to the ambient display (and in fact I had prototyped code to create graphs of the data for testing), my aim was always to evaluate the effect of an ambient display operating on its own separate from any other interface type.

From users' interview responses, they appeared to understand the flashing group notification—that when their device flashed it meant that others in the group were physically active. A higher level of "concurrent wear" is desirable to evaluate such a feature, as this maximises the potential for one user to influence another through their activity. Whilst concurrency was good, it might have been better had users been willing or able to wear their devices for longer each day.

Accuracy

Accuracy relates to users' perceptions of how well the device's activity displays reflect their own and others' levels of physical activity. Users in the study were concerned about the accuracy of the individual display:

> "I question when you have it on your wrist how accurate it is. Is it properly recording all activities?"

Another was more blunt, stating:

> "There was no visible connection between the type of exercise done and the lights."

Users who were familiar with activity categorising trackers may have been confused when the device registered non-exercise activity thermogenesis (NEAT), such as gardening, as physical activity (Levine, 2002). The wearer of a Fitbit or pedometer knows that moderate-intensity walking or running will increase their step count and that less intense activities won't. In tracking all movement, however, the wearer's usual baseline of activity is tracked along with less intense activities and the usual moderate- to high-intensity activities. This gives the appearance that the device is crediting the user for something they may not consider "true" physical activity.

This property of non-exercise activity tracking was made more confusing due to the fact that its contribution to the colour of Activmon was dependent on how long the device was worn each day. Assuming a small, yet constant, amount of "background" movement was being added to the activity counter each hour, the total counter value would be higher after twelve hours than after eight, assuming no intense physical activity during that time. Of course moderate- to high-intensity physical activity would still have a greater effect on the counter in the short-term than "background" activity, but a ten or fifteen minute cardio session might not have as much of an effect as, for example, five hours of additional wear whilst doing low-intensity activities sporadically. This may have contributed to users' doubts about whether they were really being fairly credited for more intense physical activity.

My intention was always to focus on evaluating the way in which physical activity information was displayed, moreso than the accuracy with which it could be detected. Whilst the algorithms used in Activmon needed to create a satisfactory proxy of physical activity, the aim was not to create a precise mapping between physical activity and a colour. I was therefore satisfied that the light showed a distinction between physical activity and sedentary behaviour, even if users felt particular activities weren't reflected exactly as they had expected.

Some users commented that the automatically-generated daily goal, of 5% above their first week's activity, was too easy to reach:

> "It went from red to blue [goal reached] in a single run."

> "There were about three occasions on a work day when it went blue. Blue was easy to get to on the weekend."

One user felt the daily goals were discouraging:

> "[The red-to-green display] was like climbing the hill every day."

The volatility of users' daily activity meant the goal was easy to reach on some days and was harder to reach on others. This then discouraged users or failed to provide sufficient encouragement. One user reported that, on the weekend when the goal was easy to reach, they didn't feel like doing any more activity when the light turned blue. Others reported the light turned blue only a few times during the week, possibly creating a feeling of failure on days when they couldn't reach their goal.

Clearly for some users, a goal of 5% above their week one average was too low. The four users who exceeded their week one average did so by anywhere from around 10% - 120% (Figure 4.13). The larger week two increases could have been due to users being unusually inactive in the first week or unusually active in the second week, in response to the Activmon device, or simply due to natural variances in week-to-week activity. It was not possible in this study to draw any conclusions as to which.

The group (flashing) display provided relatively little information about others' activity. Users were aware of when others were "active" but not how active they were or what threshold was being applied to generate a flashing notification. Users therefore did not have enough evidence with which to independently form a view about the accuracy of that display.

At least one user, though, speculated that the group display could be misleading:

> "It could just be one really active person."

There is an argument that the group display should therefore provide more specific information, still in an ambient fashion, about others' activity levels. For example, having separate coloured lights to represent separate users. Providing this extra information, however, whilst enhancing perceived accuracy, could either help or hinder implicit social persuasion (this is discussed in the following section—*Motivation*).

Explicit Social Persuasion

Explicit social persuasion is the property of wearable ambient displays whereby others who see them engage in discussions with wearers around the information presented. To be noticed by others the display device needs to be sufficiently attention-drawing. I was concerned, however, that this could embarrass wearers or compromise their privacy.

Users reported that Activmon did indeed draw the attention of others and engage them in conversations about the information presented:

> “When it changes to green and you’re with someone, they notice and you notice.”

Some users received surprising comments:

> “My child called it a ‘jail bracelet’ because it looks like it could be a tracking device.”

Another user said that friends had joked about their “unpaid parking tickets”, suggesting “the authorities have finally caught up with you”. This was reflected in users’ responses to the questionnaire. Despite this, in interview discussions users were unanimous in saying they weren’t concerned about others seeing them wearing the device.

Similarly, users were not self-conscious about the act of monitoring their physical activity. In the post-study questionnaire, when presented with the statement, “I don’t want others to know I’m monitoring my activity”, all four questionnaire respondents disagreed. Similarly, to the statement, “I was worried about what people would think if my light was red”, all four responded “disagree”.

The recent proliferation of commercial wearable activity trackers has brought monitoring into mainstream public consciousness. It may be that users did not consider it unusual to be wearing an activity tracker or to be sharing details about their experience of it with others. I would surmise that this trend would continue, and may alleviate any residual feelings of embarrassment and social inappropriateness for most users.

There is the possibility that, in the future, data from electronic activity trackers could also be shared with health practitioners the user sees or even made part of their personal electronic health record. When presented with the statement, “I would like my doctor to have access to my activity data”, one user responded "strongly disagree", two responded "disagree", and one responded "neutral". In interviews, participants' reluctance to share seemed to be due either to a feeling that there was no good reason to, or that doctors wouldn't have the time to analyse the data and/or be interested in it.

4.1.6 Design

The design of a wearable ambient display, in terms of size, appearance and usability, influences a user's decision to wear it, and therefore its effectiveness in conveying information. One way to indirectly measure the suitability of a device design is to measure how often and how regularly users wear it. Low or sporadic use could indicate a poor or unusable design.

In analysing the timestamps for reports on the server, I determined that two users wore Activmon on every day of the study. Another user started three days late and therefore did not return data for those days, but wore their device on every other day. Of the remaining two users, one appeared to wear their device consistently, although there was a communications failure for four days, and the other wore the device sporadically, missing a total of three days. (Figure 4.10)

Average wear time over the course of the study was eight hours per day, with a slight trend to increased wear as the study progressed and the activity display was enabled in the second week (Figure 4.11).

How consistent users were in wearing Activmon was very important in relation to the group display. The concept of having one person's activity prompt others depends on other people having their devices on at the same time. In analysing the timestamps of reports on the server ($N = 2148$), I found that for the majority (82%) of the time when one of the participants was wearing their device there was at least one other person also wearing theirs. However, very rarely were all five participants wearing their devices at the same time (Figure 4.12). Implicit persuasion is reduced during these times, as there are fewer users to generate group activity indications.

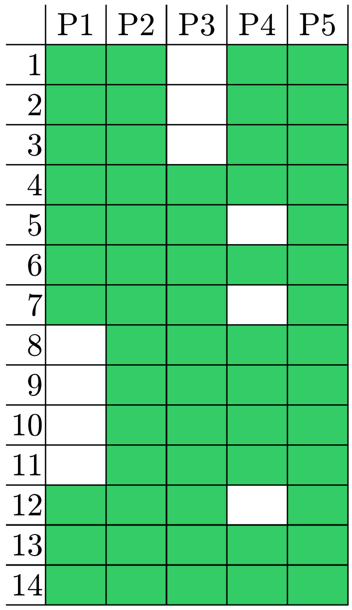


Figure 4.10: Wear per user per day. A filled position indicates a particular user returned data for that day.

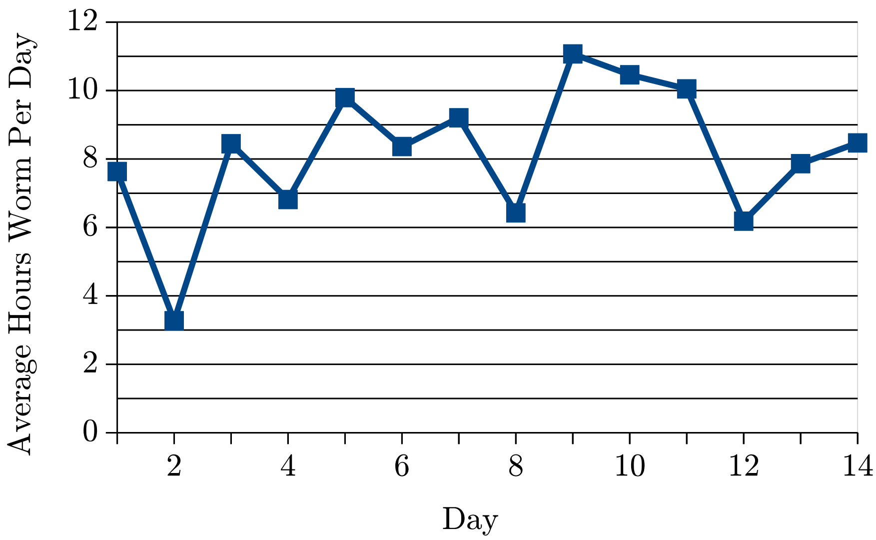


Figure 4.11: Hours the device was worn per day, averaged across all five users per day.

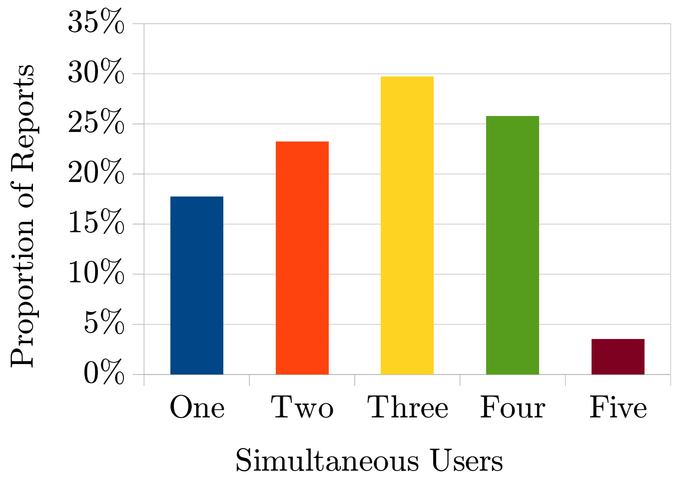


Figure 4.12: Number of activity reports where a certain number of devices were operating simultaneously

Size and Appearance

In the questionnaire, when presented with the statement "I found Activmon comfortable to wear", all responded "disagree". Female participants in particular raised this as an issue in interviews, with one commenting:

> "The device was cumbersome for a lady. I had to put it on my watch arm or else I was very aware of it."

I offered users the opportunity to suggest a different form factor for Activmon—that is, something different from a bracelet. The most common response in the questionnaire (three out of four respondents) was that Activmon could be integrated into a mobile phone. Three respondents also expressed a preference for a watch form factor. The clear preference for having a mobile phone-based ambient display is an understandable response. Most people already carry a mobile phone, so having an activity display integrated into a phone means only one device to carry around and charge. Similarly, some people already wear wrist-watches and it would be convenient for Activmon to be able to tell the time such that the user wouldn't have to wear a watch in addition to Activmon.

I have covered the benefits and drawbacks of mobile phone-based activity monitors previously (Section 2.2.4). A phone is less suitable as a physical activity sensing platform as users don't have their phone on their body continuously (Dey et al., 2011). A phone is also less than ideal for implementing an ambient display as its screen is not persistently visible, and for the user to receive any information there is the engagement pre-requisite that they are using the phone for some other reason.

In comparison, a display in the form of a wristband or watch is persistently visible and is usually worn, not carried. With wrist-worn displays becoming more popular it will likely be easier in the future to convince users to adopt them, as users will be familiar with them and they will be seen as socially acceptable.

With any wearable device there is the issue of creating a device that users will find aesthetically pleasing. With a device that tells the time there is the additional question of whether to use an analogue or digital display, or some other type of display. There is the risk of creating a device that is ill-received, not because the primary function is poorly implemented (activity monitoring) but because the user doesn't like the way the lesser function is implemented (telling time). This could negatively bias the results of any study.

In general these responses suggest that users have a preference for not adding to the number of devices they carry around with them or wear. However, the success of commercial activity trackers shows that this recalcitrance can be overcome if the device's appeal is strong enough. Being able to construct research devices such that users will be willing to accept them along with devices they already own will be an ongoing issue in this field.

It was surprising that nobody chose the option "a piece of jewellery", as I have argued previously that the device should be as small and discreet as possible and this form factor seems ideal. Perhaps the Activmon device looked so unlike a piece of jewellery to the participants that they never imagined it could take that form and therefore didn't suggest it themselves. It might also have been the case that I didn’t frame the question correctly. I didn’t believe on the strength of this question alone that the idea should be dismissed. It might not be a practical approach at the present time, however, as users’ preferences around jewellery are even more diverse than around watches.

Overall, feedback in the interviews and questionnaire responses regarding the device was negative but not overly so. The prototype was bulky and somewhat uncomfortable but not to the point where people didn’t want to wear it. The high level of compliance with wearing Activmon was promising. I felt that eight hours’ average wear time per day was good given the device was an early prototype. However the users, being colleagues, likely felt a responsibility to wear the device to help a fellow researcher and this will have biased the results.

Ease of Use

I supposed that there might be other design factors, aside from size and appearance, that would affect the usability of a wearable ambient display. Battery life and charging appeared to be such a factor. Activmon could run for around 16 hours on a single charge, although there was no “gas gauge” to let the user know when it needed recharging. Not knowing how many hours the device was likely to be worn for each day, I instructed users to recharge it nightly. I anticipated this might be inconvenient for users, both in terms of having an extra device to remember to charge and due to the need to set up a new daily charging routine.

In a study on “human-battery interaction” (HBI), Rahmati, Qian, and Zhong (2007) proposed that mobile phone users fell into two HBI categories—Types A and B. Type A users recharge their phones routinely (every 1 to 2 days) regardless of battery level. Type B users charge their phones based on feedback from the phone’s battery interface (“gas gauge” or battery bar). Activmon in its design forced a Type A interaction.

On the statement “the battery life was adequate”, one user agreed and three disagreed. On the statement “it’s inconvenient to have another device to charge”, three agreed, with one answering “neutral”. In interviews, users described the routine they established to remember to charge Activmon, with one taking to putting the charger in the bathroom where they would take off the device at the end of each day and return to put it on the next morning. Forming a daily charging habit is potentially less frustrating to the user than having to monitor a “gas gauge”, but this depends on making the act of initiating charging as simple as possible. Although comparing the two methods was outside of the scope of this research, I did show that simple charging allayed user concerns about battery life (see Section 5.3.2).

4.1.7 Motivation

Monitoring

All users said in post-study interviews that they noticed the individual activity light change colour during the study. The brightness and visibility of the light appeared to have the desired effect of prompting users to look at the display:

> “The brightness was a good level... when it changes colour you notice because it’s bright”

Users’ devices delivered a large number of group flashing notifications in week two. A total of 146 notifications were delivered to the five users with each user seeing, on average, one notification for every 90 minutes they wore Activmon. When asked, “Activmon got my attention when it started flashing”, two users responded “agree” and another “strongly agree”. This was reflected in interview responses with all but one user stating they noticed the flashing/pulsing at least once during the second week of the study.

Reflection

Interview and questionnaire responses showed that the devices prompted users to think about their own levels of physical activity and those of others. For one user, this reflective process was particularly enjoyable:

> "When it starts flashing you wonder who's exercising. It's a bit of fun."

Another felt the group display motivated them to be more active:

> "When it started flashing I thought 'I should be doing some exercise'. It brings out your competitive side. It put me into a panic when it started flashing and I couldn't go and do exercise."

Knowing the identity of active group members could enhance the sense of competition between users, but it could also create a disincentive. Bandura states that self-efficacy is increased by way of social modelling when people identify models as being similar to themselves (Bandura, 1991). If the anonymous active user or users are revealed to be a "gym junkie", then a less active user may feel disinclined to model their behaviour on that person. Or, if it were known that only one user was doing the majority of the activity, the other four users may feel comfortable to remain part of the inactive majority, hiding among the crowd and seeing their inactivity as a social norm. I felt the anonymity or otherwise of users in the group notification system remained an open question.

Engagement

Monitoring and reflection are two important aspects of a behaviour monitoring intervention such as Activmon—users must view the information displayed and then reflect on it to create personal meaning. To realise actual behaviour change, however, users must then engage in an ongoing process of monitoring and reflection.

Participants' engagement with Activmon was mixed. One user commented:

> "It takes more than a glowing light to make me exercise."

clearly indicating they didn't find the ambient display particularly motivating. However, another said:

> "I was far more aware of exercise wearing [Activmon] than not wearing it. I feel I did more exercise because of it"

indicating they engaged with the display and felt that it had some motivational effect.

I have previously discussed the problems with using measures of actual physical activity in short-duration studies to gauge efficacy (Section 3.2.3). Actual activity data, however, are a valuable addition to the data received through questionnaires and interviews, and can add weight or contrast to any findings from these qualitative instruments.

Out of the five participants, four had a higher second week average activity level, and all four exceeded their goal of a 5% increase over their first week average (Figure 4.13). However, in questionnaire and interview responses the participants were split on the question of whether they felt Activmon had motivated them. Two found the device helpful, another two reacted negatively to the device, and one felt it didn't provide them with enough information.

Interestingly the qualitative results didn't align with the quantitative results, with activity counter data showing a response by users who professed not to like the device. This could have been due to users unconsciously responding to the display, or perhaps their dislike was not enough to prevent them engaging with the display. Alternatively they may have made an effort to engage when they otherwise wouldn't, in order to assist with my research.

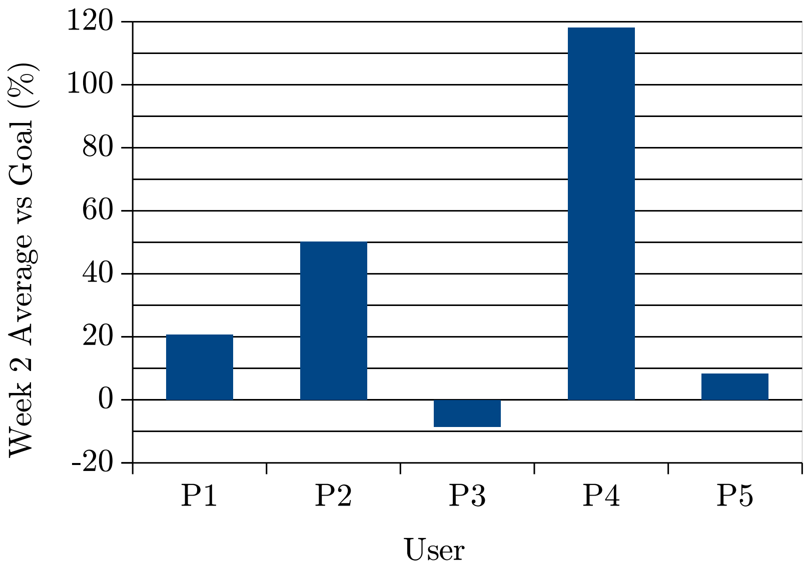


Figure 4.13: Users’ week 2 average activity as a percentage of their individual goals

4.1.8 Discussion

Through the Activmon study I validated my preliminary wearable device design, individual and group activity displays, and the underlying algorithms used to produce them. I showed that users were able to comprehend the individual and group activity displays, and that those displays prompted them to think about their own physical activity and that of others. Further, some users demonstrated a willingness to initiate a deeper engagement with their own physical activity—something that could potentially lead to behaviour change if sustained in the medium- to long-term. Although the low-fidelity Activmon prototype was bulky and uncomfortable, I demonstrated that it was useful and practical in real-world usage.

From user feedback, however, I discovered a number of issues:

- The individual display did not adequately account for the variable nature of physical activity from day to day. The result for some participants was a demotivating feeling of being ‘at the bottom of a hill’ every day.

- Having a fixed goal each day meant the goal was easy to achieve on some days and unachievable on others.

- The device's activity recording was not accurate or did not yield a sufficient appearance of accuracy. Participants were doubtful of the feedback from the device.
- The group display was effective at informing participants when other participants were exercising, but did not provide enough information to adequately enable the emergence of any social dynamic. Participants wanted to know who was represented by the flashing notifications.
- The device was too bulky and unappealing, and not user-friendly. It is possible that retention rates in a longer-term study with members of the general population would be low as a result.

4.2 "Activthings"

From the findings of the Activmon study I was able to propose a new set of goals to guide the development of a new ambient display device and activity displays, which I would collectively refer to as "Activthings". These goals were as follows.

Goals for improvements in information presentation:

- Modify the logic behind the individual display to increase perceived accuracy and user satisfaction.
- Adapt the group display to provide higher-fidelity social data.

For improvements in design:

- Reduce the size of the device as much as possible and give it a more professional appearance to encourage users to wear it more often and increase social acceptability.

- Give the ambient display the ability to adjust to the brightness of the user's environment to make it more appropriate in a variety of social situations.
- Make it easier to recharge the device, in order to aid habituation of the charging process (Type A Human-Battery Interaction).
- Adapt the device to be more user-friendly in all stages of operation, giving a user information about its connection status, to improve confidence that it is working as intended and to aid in troubleshooting.
- Make the device compatible with as wide a range of phone models as possible, to allow users to connect their own phone rather than one I would have to provide.

The goals of creating a user-friendly interface and improving phone compatibility were not as a direct result of user feedback. Rather, I intended in future to allow users to connect their own phones with the device rather than having them use a phone that I provided. This requirement drove the need for greater compatibility and a simple interface to allow users to "pair" their own phones.

4.2.1 Continuum-Based Individual Display

Participants in the Activmon study said that it was demotivating to see the individual activity display reset at the beginning of each day, with one likening it to constantly climbing the same hill. They also reported that the fixed daily goal could be demotivating on days when it was difficult to be active enough to reach the goal. The fixed goal didn't properly reflect the variability of users' real-world activity—for example, an office worker might find the goal easy to reach on the weekend when they can walk or play sport during the day, but harder to reach on weekdays when they are required to be at a desk.

I considered that a better approach would be to encourage and track consistency of activity over the medium-term, rather than tracking short-term (daily) trends.

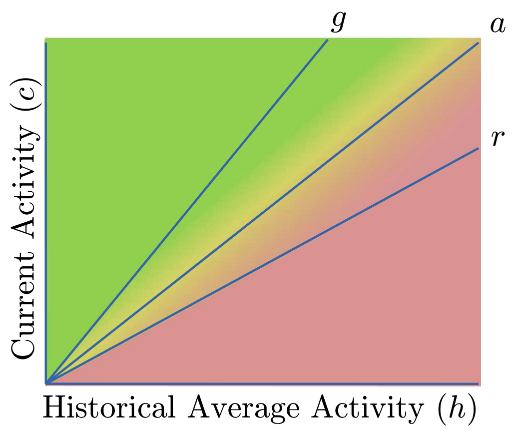


Figure 4.14: The continuum activity display where c is an average over several days

Rather than showing users’ activity for a single day in comparison to a daily goal, I could show users’ average levels of activity over a longer period of time—such as a week—in comparison to their historical average activity levels.

The goal would then be to increase one’s weekly average above the long-term trend. In terms of an ambient display, red, yellow, and green could represent average activity levels over the past week that are lower than, equal to, or higher than the user’s historical average activity levels.

I hoped that this “continuum” display might alleviate the Sisyphean feeling of daily “hill climbing” reported by participants in the Activmon study. It would also smooth out short-term volatility in their daily activity levels, potentially decreasing the perception of inaccuracy. The tendency of the display to reflect non-exercise (NEAT) activity as if it were exercise activity would also be reduced.

Figure 4.14 illustrates this continuum display as I decided to implement it in the Activthings device. As before, at the end of each week the user’s historical activity level h is calculated as an average of daily activity over the past week. A new daily goal for the coming week g is set at some level above h, in the range of 5–10%. However, current activity c is no longer reset at the beginning of each day. Instead, c is calculated as an average of current and past daily activity over a seven day ‘sliding window’.

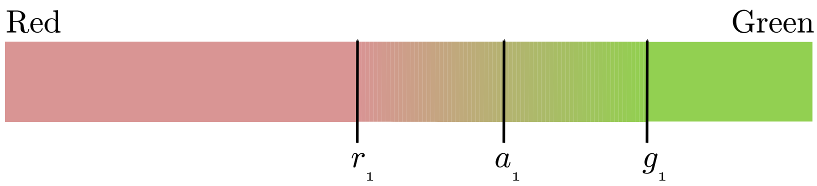


Figure 4.15: An example of the continuum display

The region over which the light changes from red to green no longer starts at $c = 0$ but instead is bounded at the green end by the goal line g and at the red end by a new "red line" r. As the user's current activity level c approaches g, the light will turn green. If c drops to a and then to r, the light will change through yellow to red.

As an example, imagine that we have already collected a week's worth of activity data from a user. With reference to the continuum shown in Figure 4.15, let her average activity level over the past week be a_1. Her goal g_1 is to try, over the coming week, to sustain a new average activity level greater than the previous week. At the start of the week her current average activity level over a seven day sliding window will equal her previous week's historical average ($c = a_1$), and she will receive a yellow indication.

Assume that she is very active on the first day of the week. Her current average activity level will rise toward g_1 and she will receive a green indication. Assume then that she becomes busy with work the next day and is very inactive. Her current average activity level will drop back toward a_1 and she will see a yellow colour again. If she is inactive the next day as well, her activity level will drop further and as she approaches r_1 she will see a red colour. She may then compensate with more activity over the next few days and move her activity level back toward g_1 and therefore into the green zone. As there is no finite goal or terminal point for each day, there is no need for an explicit "goal" indication, such as the blue light in the Activmon system, described previously. If the user's average activity exceeds their weekly goal, the light will simply remain green until their average decreases again.

In the Activmon system, perceived difficulty is determined by placement of the goal line, g. If g is too high for a particular day, then the light will be difficult to turn green and the user may be demotivated. If g is too low, the light will be too easy to turn green and the user may not feel a sense of achievement from doing it. Users in the Activmon study expressed a dislike for this focus on short-term daily goals.

The continuum approach of Activthings, on the other hand, focuses on longer-term trends and consistency. This will tend to smooth out short-term fluctuations in activity and provide some leeway for "lazy" days. There are, however, now two variables affecting perceived difficulty—the goal line g and the red line r. The closer r is to a, the less leniency there will be when the user has inactive days. The closer g is to a, the easier the goal will be to achieve.

Finding the right settings for both of these variables is important to create a goal that is challenging without being demotivating, and a system that allows for some recidivism but discourages excessive sedentary behaviour. I decided that these variables should be set such that it would take more than one 'good' day to turn the light completely green, and more than one day of low physical activity to turn the light completely red. It would have also been possible to allow users to select their own goals, and there is a separate body of research on this subject. For the purposes previously discussed in Section 4.1.1, however, I decided to pre-select goal determinants for users.

As with the Activmon approach, there is the need for a "training period", where activity data are collected for a number of days in order to create an initial goal. Without these data and this goal it is not possible to create an accurate activity display for the user. The Activmon training period was seven days, but I felt this was too long for an extended study. Given the need to hold the interest of users over a long period of time, it seemed important to present an activity indication as soon as possible, even if it was somewhat inaccurate. I therefore settled on a training period of at least three days and a total of 24 hours of collected data, ensuring a minimum quantity of data as well as a minimum length of time.

A practical problem in implementing the continuum approach in a device was that of daily wear time affecting the user's activity average. It's reasonable to assume, at least for less active people, that most of the day will be spent engaging in sedentary behaviour (such as sitting) interspersed with short periods of physical activity (walking, running and playing sport) The longer the device is worn during these sedentary times, the more that sedentary activity would tend to drag down the user's average activity level in spite of them engaging in physical activity.

Consider for example a user who runs for one hour, recording an activity rate of 1000 counts per hour (cph), and who then sits for three hours, an activity rate of 100 counts per hour, before turning the device off for the day. Their average activity rate for the day will be 325 cph. The next day the same user runs for one hour then sits, wearing the device, for five hours. Assuming the same activity rates, the user will have an average daily activity rate of 250 cph. They may have sat for the same number of hours on day two as for day one, but they are essentially penalised just by wearing the device for longer on the second day.

The problem, statistically, has to do with missing data points. It is not reasonable to assume that a person will wear the device every hour of every day, therefore there needs to be some way to acknowledge and account for the times when the device has been unable to track the user's activity. I proposed the simple solution of imputation, filling in hours for which data points were missing with the user's median activity rate. If the user's behaviour follows the expected pattern of mainly sedentary activity with some physical activity, the physical activity is effectively an outlier. Using an outlier-resistant measure of central tendency, such as the median, is an effective means to capture the underlying rate of sedentary behaviour, given this distribution (Appendix Section B.2). This will then account for times when the user's device is turned off, effectively assuming the user was sedentary during those times. Median imputation is also simple to implement and verify.

In practice, the individual activity calculation would proceed as follows. The user would wear a device with a three axis accelerometer, capturing acceleration in three dimensions, x, y and z. After filtering to remove noise and static acceleration (due to gravity), the device would calculate the magnitude of the acceleration vector from the three acceleration components. If this magnitude were over a certain threshold it would be added to an "activity counter".

As with the Activmon approach outlined previously, at a certain interval the device would calculate a_i, the rate of change of this counter, as:

$$a_i = \frac{c_i - c_{i-1}}{t_i - t_{i-1}} \tag{4.11}$$

where c_i is the current activity counter value, c_{i-1} is the activity counter value as of the last rate calculation, and $t_i - t_{i-1}$ is the time difference between the present and previous rate calculations, expressed as fractional hours.

Before calculating the user's sliding window average activity rate for a particular period, it is necessary to decide the extent to which median imputation is required to account for missing data in that period. In order to avoid suppressing the effects of outliers (physical activity), imputation should only be performed for days where valid activity rates have been collected.

Assuming activity rates are calculated at fixed periods of t_{rate} seconds, it is possible to calculate m, the required number of imputed measurements, as follows:

$$m = (\frac{d_{valid} \times s}{t_{rate}}) - n \tag{4.12}$$

where d_{valid} is the number of days within the sliding window period with valid measurements, s is the number of seconds in a day, t_{rate} is as above, and n is the number of valid measurements.

The sliding window average activity rate avg_i, with median imputation, can then be calculated as:

$$avg_i = \frac{1}{m+n}((\sum_{j=i-n+1}^{i} a_j) + (m \times median(a_0 \dots a_n))) \tag{4.13}$$

where m and n are the number of imputed and actual measurements, respectively, in the sliding window, and a_j represents a measured rate of physical activity.

4.2.2 Improved Accelerometer Processing

As previously discussed (Section 4.1.3), there were a number of hardware and software limitations for the initial design that affected the accuracy of processing of accelerometer data. I was only able to read accelerations in two axes, the simple algorithm I used didn't calculate precise acceleration vectors, and activity rates were only calculated every 15 minutes. It was important to address these limitations in the new design so that users would have confidence the device was tracking their actual level of physical activity.

In the design for the new Activthings hardware, I ensured that all three outputs of the accelerometer (the x, y, and z axes) were connected to the CPU and could therefore be sampled. I developed software to sample each axis quickly enough that I would be able to capture all significant frequency components of human motion (in this case, at 122 Hz). The software then passed the acceleration data through a high-pass filter, which attenuated acceleration components with a frequency of less than 2.8 Hz., in order to remove the effect of static acceleration (gravity). This was higher than ideal (Fujiki (2010) suggests a maximum of 0.5 Hz), however it was unavoidable given the way the filter was implemented, and my testing showed the attenuation of physical activity components was acceptable.

To precisely calculate the magnitude of the acceleration vector, the Activthings software summed the squares of the acceleration values in each axis, and calculated an approximate root using a successive squares approximation algorithm. This algorithm allowed the root to be calculated quickly by making use of hardware integer multiplication, but introduced some inaccuracy to the result. To counteract this I applied a threshold to the resulting magnitude, rejecting those that fell below the threshold[2]. I added the remaining "significant" accelerations to the activity counter.

I provide an initial validation of this new algorithm in Appendix Section B.2.

4.2.3 Higher-Fidelity Group Display

A key finding of the Activmon study was that users wanted higher-fidelity social feedback. Although users already seemed to benefit from having an aggregate, anonymous indication of group activity, being able to identify individuals in a group could be more conducive to generating the feeling of a social environment around the device. The challenge was to design an interface to show individualised group activity that was simple, intuitive, and visually appealing.

The first design I considered used multiple RGB LEDs, where each LED consistently represented a separate person. One of the LEDs showed the device wearer's activity, with the others showing the activity levels of other group members on the same red-to-green scale. However, the LED position-to-person mapping in this approach was be non-obvious. The wearer had to remember which LED position corresponded to which person, including their own LED, and the positions needed to be manually labelled on the device itself in case they forgot. This added complexity invalidated the role of the ambient display as a display that could be taken in at a glance.

I considered that, in the Activmon study, users' primary concern regarding the group activity display was that the activity of others was only presented in aggregate. Users were unable to compare their own activity directly to that of others, and this created distrust of the information presented ('is it just one really active user

[2] I determined an appropriate threshold, through experimentation, that excluded small acceleration values due to noise yet still captured actual user movement.

[generating an activity indication]?'). Users did not, however, express a desire to see how those other users were performing against their own goals. I decided, then, that this granularity of information was not necessary and that a simpler form of group representation was possible.

I therefore developed an alternative design which used fixed colours as a way to identify individuals, and a positional ranking system as a way of providing a user with a method of gauging others' activity in comparison to their own. Each individual in a group of users with linked devices was assigned a consistent colour. This connection between user and colour was made clearer by having each user in the group wear a device of that colour. For example, Alice might have a device made of a blue material, Bob might have a cyan device, and Carol might have a magenta coloured device. However, the user's colour would not necessarily be seen as part of their own display.

The devices themselves would have several RGB LEDs arranged in a straight line. A single middle LED would consistently operate in the same way as the Activmon LED but with the new sliding window continuum display, changing from red to yellow to green depending on the wearer's own physical activity. The LEDs above and below this middle light would turn on and off and change colour to show a visual ranking of other users in the group based on their progress toward their goals. Users would be ranked on how close they were proportionate to their own goals to create a fair ranking. LEDs above the middle light would represent others who were doing better than the wearer. LEDs below the middle light would represent others who were not doing as well as the wearer.

Let's assume, for example, that Alice is well progressed toward her goal. Bob isn't doing as well. Carol has been very inactive and is the furthest of the three from her own goal. Alice's middle light (her individual light) would show a mostly green indication. Below this light she would see a cyan light and a magenta light (representing Bob and Carol who aren't doing as well as her).

Bob would see a blue light above his middle light (representing Alice) and a magenta light below his middle light (representing Carol). Carol would see both Alice and Bob (represented by blue and cyan lights) above her middle light, showing she is least progressed toward her goal compared to the others in the group. Her individual light would be mostly red, showing her that, individually, she is far from her goal. (Figure 4.16)

In implementing this display I chose to limit the maximum number of users per group to five. With $N = 5$ users, $N + N - 1 = 9$ LEDs in total would be required. This seemed a feasible number given the maximum size of a wrist-mounted device, and the desire to not have so many lights as to make the display overwhelming. A total of $N = 5$ user colour codes would be needed, although only $N - 1 = 4$ distinct colours would be displayed at once. This is possible using the primary (red, green, blue) and secondary (cyan, yellow, magenta) colours, and white. More users would require more unique colours, which may be difficult to create with RGB LEDs and may be hard for users to tell apart.

Note that for the purposes of ranking users within a group, the sliding window period used to calculate users' activity averages need not be the same length as the windows used to calculate users' goals or individual activity indications. A shorter window will tend to rank users on recent, short-term activity whereas a longer window will tend to rank users on consistent long-term activity.

This ranking approach has a number of advantages over the flashing notification used for the Activmon device. It reveals each user's activity individually rather than anonymising them in a single indication. At a glance the wearer can see how group members are performing in relation to one another, as well as seeing where they are in relation to the group. If they are interested there is the opportunity to track other group members' activity over a period of time.

This provides an element of social context for the wearer's individual activity. It also enables social dynamics involving competition and co-operation between group

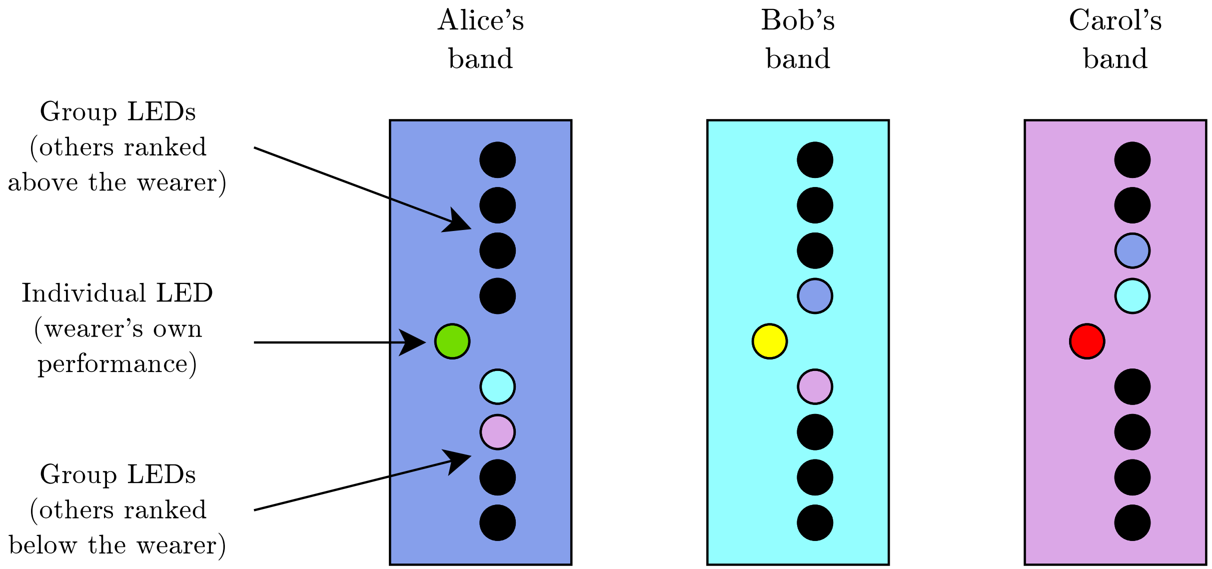


Figure 4.16: A ranking display for three users

members. If a group is made up of people who know one another, it is necessary for them to learn a mapping between people and their colour codes. However, even without knowing or remembering exactly who each colour represents, users can relate to them as individuals. Colour mappings are potentially easier to understand at a glance than positional mappings and do not require textual labelling.

There are potential downsides to this new group display. By moving away from a flashing notification, some of the immediacy of the group display is lost. The changing positions of the colours are less conspicuous than a single light that flashes at the wearer. Having said that, I was unable to determine in the Activmon study whether users were actually prompted to change their behaviour as a direct result of seeing the light flash. Arguably, if a user is already occupied with sedentary activity, they may not be willing to engage in physical activity even if they notice the light flash. A ranking display is potentially more useful as it provides a persistently visible measure of group performance without the annoyance of seeming to directly prompt users to engage in behaviour they are not primed to undertake.

Although the new display answers the fundamental question of “how active are others?” it still does not provide any specific information about the actual activity of any particular user. This was a conscious design decision—providing information that was too detailed might make the display harder to understand at a glance and confuse users. However, rather than deny this information to users if they wished to see it, I would propose that in future it could be provided through some other means such as a phone app or website. It was, however, outside the scope of this research.

4.2.4 Update Frequency

The previous Activmon software sent the calculated activity counter value to the server every 15 minutes whereupon a new activity rate was calculated. Given the new group ranking system and focus on consistency and longer-term trends, 15-

minute updates to the server seemed excessive. Rankings demand less immediacy than the previous flashing indication, and given users will not be deliberately drawn to the ranking display through a notification-style indication, they are unlikely to notice if rankings change more slowly. Running the Bluetooth radio less often would help to conserve battery life and allow the device to use a smaller battery. Connecting less often would also place less strain on the batteries of users' phones and cost less money in data use.

I decided to have Activthings connect to the server hourly. However, I didn't want to return only one data point an hour as this would fail to adequately capture short periods of physical activity. I therefore implemented a new algorithm where the device itself would calculate an activity rate (at a faster rate of once every five minutes), update the individual activity display as appropriate and cache this rate in memory for later upload to the server.

In order to update the individual activity display, however, the device would need to use the activity rate for the previous five minutes to calculate a new seven day sliding window average. Ordinarily this would involve summing the activity rates, and imputed rates, over the seven day window σ and dividing by the number of rates n (see Equation 4.13). Whilst this could be done on the Activthings device itself, it would have required a significant amount of memory (to store seven days worth of rates) and processing power.

Instead I decided to use a scheme whereby the device could calculate a new running average using the partial products of the last average calculation performed on the server. Whenever the Activthings device made its hourly contact with the server, the server would generate the σ and n components of the sliding window average and return them to the device. The device could then compute the average, by dividing the σ value by n, and use this value to set the colour of the individual LED with respect to the upper and lower activity bounds (which would also be supplied by the server). Every five minutes thereafter the device would generate a new average, by adding the current activity rate to σ and dividing by $n+1$, and use this to update the individual LED if needed.

Obviously, averages generated between server contacts are only approximations. The server generated σ and n are only valid at the time they are generated by the server, t_0. At $t_0 + 5$ minutes the correct way to create a new sliding window average would be to remove the oldest data point used to create the previous average, at $t_0 - 7$ days, before adding the new data point $t_0 + 5$ minutes. Having only σ and n the device has no way of doing this, therefore the new average effectively reflects a period of 7 days plus 5 minutes. In reality, given n is likely to be large, this deviation from the actual average shouldn't be noticeable and the deviation will only increase until the next server update, at which time it will return to zero.

I expand on the design of the Activthings device-to-server protocol in greater detail in Appendix Section C.6.

4.2.5 Housing

The Activmon preliminary prototype used an ad-hoc housing that I constructed using a plastic sheet and silicone wristband. Although it was functionally suitable for purpose, it was not aesthetically pleasing and looked quite bulky, especially when worn on a small wrist. In designing and manufacturing a casing for the new prototype device I had access to a 3D printer, and I therefore had a great deal more flexibility in creating a more customised housing. I resolved to build a case with curved "organic" features. For the casing to be comfortable for long-term wear, and especially for wear during exercise, it seemed important to have it follow the line of the wearer's wrist. This would also tend to reduce the appearance of bulkiness given the relative thickness of the battery and electronics that needed to fit inside.

As I was no longer using a casing with a built-in band, I also needed to choose a wristband with which to attach the device to the user's wrist. It needed to be aesthetically pleasing if possible. It needed to be adjustable to different wrist circumferences so that it would fit a range of users both male and female. It needed to be comfortable to wear for long periods and during physical exertion, and not cause rubbing, pinching, and marking or become overly "sweaty". I decided to use woven elastic for the band, paired with a Velcro fastening. Elastic and Velcro are designed for use in wearable products and therefore should not cause any major injury to the wearer. Velcro also offers the possibility of flexibility in fastening without a complicated latching system.

In a traditional design situation, a custom plastic casing would need to be designed, then sent to a facility to be produced. The requirement to interface with a production facility would add a lot of time and expense to the process, and there would be a high amount of risk that the end product would not be suitable, as the design will only be iterated through on paper before a financial commitment must be made to a prototype. Even with high confidence in a design, the expense of converting this design into an object that can be produced is such that it is impossible to justify unless a large number of devices are to be produced. This is a problem that has curtailed the development of custom high-fidelity wearable device prototypes in the field of Human-Computer Interaction (HCI), forcing a reliance in previous literature on software that can be loaded into existing devices, mainly smartphones.

3D printers put all the power to control the design process back in the hands of the researcher. A 'home' 3D printer represents a moderate one-off expense, after which the cost of the filament that items are printed from is extremely low. Therefore if an initial prototype is produced and a small flaw is found in its design, the production of the improved next iteration is an equivalently small expenditure of time and money. There is a learning curve in terms of the researcher needing to understand how the new tool works, and if a 3D-printed prototype is to be later turned into a professional-grade prototype, this translation process may be non-trivial. Nonetheless, 3D printing dramatically lowers the barrier to creating highly custom research devices that are satisfactory for deployment in real studies.

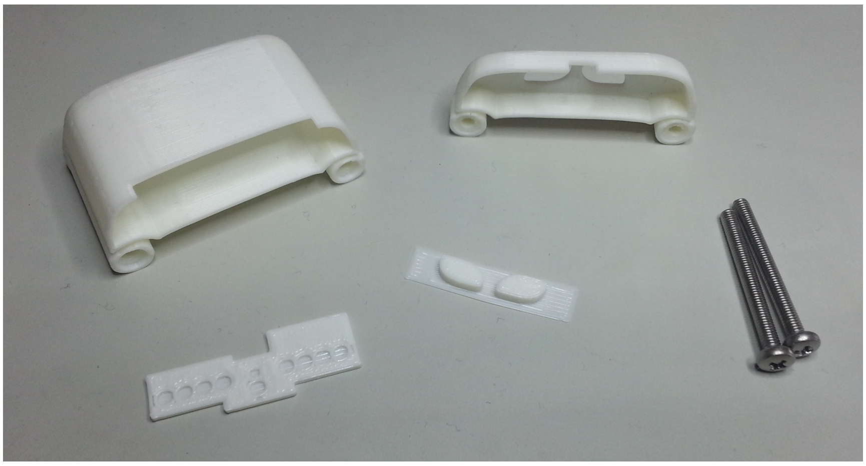


Figure 4.17: 3D-printed housing parts. Clockwise from top-left: case, end-cap, screws, buttons, light disperser.

With the aid of the 3D printer, I was able to start by designing a device casing that was as small as possible given the electronics that would need to fit inside of it, and of a close-to-ideal appearance given the trends towards soft-edged and curved devices in the commercial wearable space. I was then able to evaluate this device in practice and make modifications to improve the appearance and comfort. This rapid prototyping process also enabled me to tie the design of the casing in with the design of the electronics in ways that would have been otherwise difficult.

After a great deal of experimentation (see Appendix Section C.3), I arrived at the design shown in Figures 4.17 and 4.18. The electronics and battery are contained inside the housing, which is constructed of two pieces of printed plastic held together by stainless steel screws. The screws additionally act as electrical contacts for when the device is mated with a charging cradle (Section 4.2.6). The two screw poles attach the wristband, which is made of 25mm woven elastic with sewn Velcro fasteners. Although the casing was not waterproof I tested it to confirm it could withstand splashes of water, consistent with what might be experienced wearing it when washing or in the rain.

There were two important considerations in the design relating to the presentation of the ambient display. The first was how the LEDs, which were mounted on the

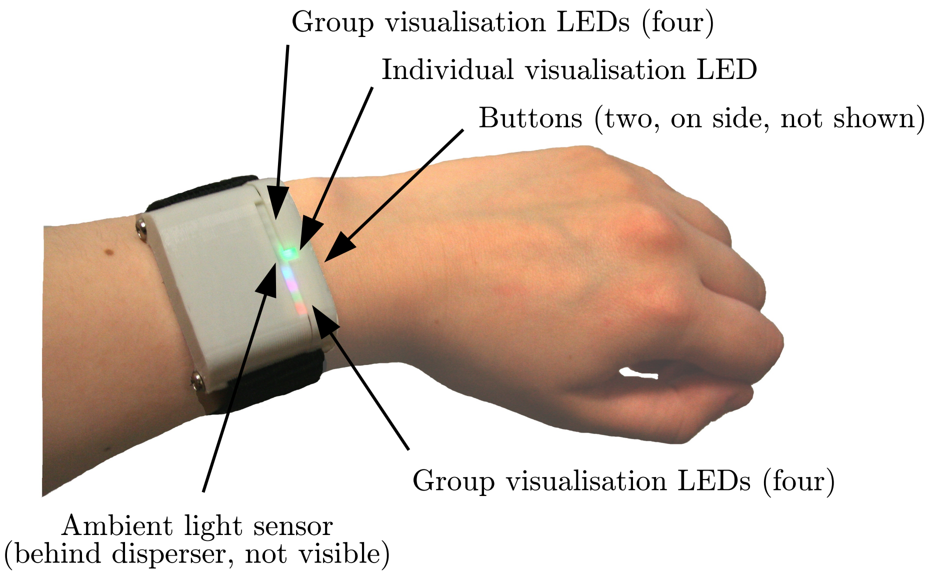


Figure 4.18: The Activthings device

electronics contained inside the housing, would appear once the device was assembled. Due to limitations in the resolution of the printer, it was not possible to create openings in the case for the individual LEDs. The printed casing was translucent, allowing light from the LEDs to be visible from outside even with a completely closed case. However, for this device I had added a sensor to detect the level of ambient light falling on the face of the device so that the LED brightness could be adjusted to ambient brightness, and this sensor could not function in a completely closed case.

The second issue was how to clearly differentiate the LED representing the wearer from the numerous other LEDs that would be required to implement the updated group display. There are nine RGB LEDs in total inside the Activthings device: the central one for the individual activity display, and eight for the group activity display. There are four LEDs above the central individual LED and four below, ensuring that the wearer can be both at the top and bottom of the rankings without their individual LED appearing to move positions. However, it may still be difficult for them to locate their LED at a glance, and needing to concentrate on this problem would invalidate the ambient nature of the display.

To solve this problem, I mounted all of the LEDs inside the device in a straight line with the exception of the central individual LED, which was slightly offset from the others to make it stand out. I created one large T-shaped opening in the housing through which all the LEDs could be seen. So that the internals of the device would not be completely exposed I created a thinner plastic insert to fit into this cut-out, covering the board and LEDs inside the device while still allowing the sensor to function properly. This insert also served the function of a light collimator/disperser, forming the light from the LEDs below into soft round dots.

I also added two buttons to the Activthings device that could be used to drive its simple user interface (Section 4.2.7).

I expand on the design of the Activthings hardware in greater detail in Appendix Section C.1.

4.2.6 Charging Cradle

Although on the whole I hadn't identified charging as a significant issue in the scoping study, I decided some improvements should be made to the charging function in the design of the Activthings device. In particular, the approach of plugging a charging cable into the device itself seemed 'fiddly'—the cable could be difficult to insert (it could only go around one way) and could get tangled up or lost on the floor amongst other cables. Considering users would need to successfully charge the device in order to continue using it, I felt that the process should be more straightforward, such that daily charging would become a simple and habitual activity.

I decided the easiest way to facilitate a charging habit was to create a charging cradle for the device. At the end of the day when the user removed Activthings, they could snap it into the cradle and it would recharge overnight (Figures 4.19 and 4.20). This approach also had the advantage of providing a fixed location for

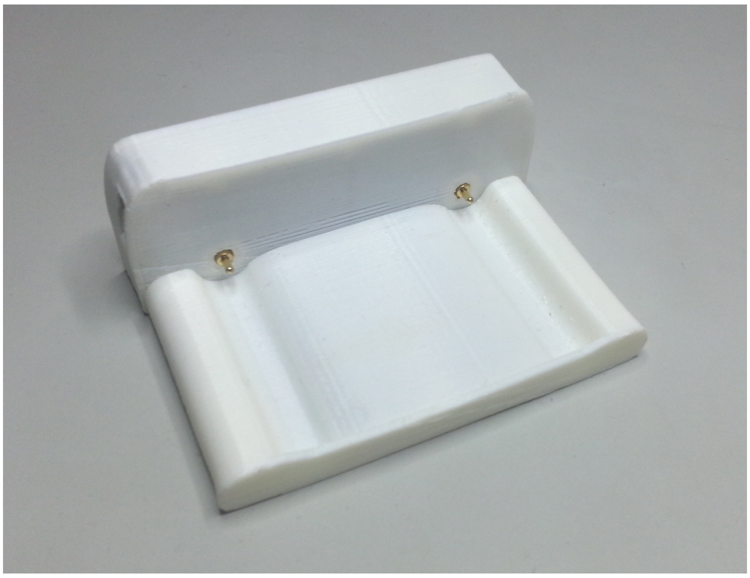


Figure 4.19: The charging cradle, showing gold spring-loaded pins that mated with the screws on the Activthings device

the user to put the device when not wearing it, so it would be less likely to get lost and easier for the user to locate to put it back on the next day. In contrast to the previous design, there would be no need for the user to move a physical on/off switch or handle cables regularly. The device would automatically detect when it was placed in the cradle and start charging immediately, and when removed from the cradle would go back to normal operation. When the device was in the cradle the middle (individual activity) LED acted as a charging indicator, turning red to show charging and changing to green when charging had completed.

I expand on the design of the Activthings power and charging hardware design in greater detail in Appendix Section C.4.

4.2.7 Enhanced Feedback

The Activmon prototype gave the user no feedback as to the status of the connection with the user's mobile phone and the server, and it was permanently associated with a single phone. If the device lost its connection to the phone or the server, it would

Figure 4.20: The Activthings device mated to its charging cradle

silently retry the connection indefinitely. Whilst the individual activity display would still update, the group display would not operate correctly, and the user had no information that might help them fix the problem. The user was also unable to associate the device with a different phone if needed.

To address these limitations, in the Activthings device I implemented a simple user interface that operated using a combination of the RGB LEDs and the two side buttons. When the device was switched on for the first time, it would show two blue lights to indicate it was ready to pair with a phone. It would find the first phone that was “discoverable” via Bluetooth and attempt to make a connection. The two lights would change to yellow and then green as the device contacted the server, after which the usual ambient display would be shown. Holding down the lower side button at any time would force the device to forget its phone pairing and re-enter pairing mode. This allowed the user to connect the device to a different phone if it had been paired incorrectly or the user wished to use a different phone to the one it had been paired with previously.

The device would subsequently attempt to re-establish a connection with the server every hour in order to send and receive updated information. If the device could not connect, it would retry 30 minutes later and then again after a further 30 minutes. If the device still could not connect it would display two red lights, deactivating the ambient displays completely. The device would keep attempting to connect every 30 minutes thereafter, or until the user switched it off and on again to cause it to attempt to re-connect immediately. This ensured users would be aware of problems with their device and would be able to seek relevant help.

I discuss the Bluetooth interface in greater detail in Appendix Section C.5.

As previously mentioned (Section 4.2.6), the device would enter charging mode automatically when inserted into its cradle and enter operational mode immediately after it was removed. Additionally the user could switch the device on and off manually by holding down the upper side button.

4.2.8 Initial Validation

As an initial validation of the new device and individual display, I wore the device myself for several weeks in a variety of sedentary and active situations. I found the individual display reflected my level of physical activity, and the device was comfortable to wear. I noted that the location I wore the device was significant—if I wore it on my ankle frequently (such as when exercising on a treadmill), I later received less credit for other activities when wearing the device on my wrist.

I discuss this evaluation process in full in Appendix Section B.2.

4.2.9 Study Design

To evaluate Activthings I planned to undertake a study involving 40 users each wearing the device for six weeks (40 devices in total). I would divide the participants into groups of five, each receiving a variation of either the individual or group activity display, or both displays in combination. I would ask the participants to complete a questionnaire at the end of the study, which would include questions targeting the three categories of evaluation criteria in Section 3.2—information presentation, design and motivation. In addition I would ask participants to complete pre- and post-study questionnaires to measure self-efficacy and self-reported physical activity. I would also analyse physical activity data, as measured by the wearable devices, to aid interpretation of these qualitative measures.

The aim of this study, as with the Activmon study, would be primarily to collect qualitative data to address my research questions (Section 1.4). That is, how best to present information using wearable ambient displays, which properties of those displays affect acceptance and ease-of-use, and whether users are willing to engage with monitoring the information presented. With five users per group—a total of eight different conditions—I could test a range of different variations of each display type. I decided that, in the context of HCI research, it would be more valuable to provide qualitative data on a range of design variations as opposed to trying to collect quantitative data on a smaller number of conditions.

I realised that I had two different motivators to evaluate: the individual display, consisting of Activthings' middle light that changed colour depending on the user's level of physical activity, and the group display, consisting of Activthings' other LEDs, that showed a ranking of users within a group. To see what effect each display had in isolation and combination, I decided to provide some users with the individual display only, some with the group display only, and some with both displays together.

I also needed to determine the optimal parameters for each display according to their new functions. For the individual display, I wanted to determine an effective automatic goal-setting mechanism. In the Activmon study, I had used a goal of 5% above each user's average activity levels. In this case the goal had been too low—most users exceeded it by a significant margin in the second week of the study. However, the new continuum activity calculation was designed to be much more robust to short-term changes in physical activity, and therefore a lower goal might be suitable. I decided to test this original 5% setting as well as a 10% increase.

In terms of the group display, I mentioned previously that users' average activity levels for the purposes of ranking need not be calculated over the same sliding window as used for the individual activity indication. In fact it may be preferable to use a shorter window, for example three hours. This would make it possible for a user at the bottom of the rankings to rise to the top simply by being more active than other users in the group over the past three hours. Making it easier to rise up the rankings, and allowing each user to spend some time in the lead position, may foster more positive feelings about the group display leading to a more encouraging effect. It will also make it more likely that users will see change in their group display, giving them confidence that the display is working. I therefore decided to evaluate two opposite extremes: a three hour window against a seven day window (where users were ranked against their past week's activity versus their goal).

As with the evaluation of Activmon, the participants I recruited would wear the Activthings device for a period of time in real-world conditions. Given I wanted to evaluate variations of the two displays, I decided to define a number of different conditions into which study participants would be assigned. As the design of Activthings limited the group display to five users, each of the conditions employing the group display would have one group of five users each. For convenience, I decided that conditions employing the individual display would also have one group of five users each[3].

I defined four conditions that focussed on evaluating the individual display, each with different goal line and red line settings. Users in the first group (condition A1) would receive goals 10% above their average activity levels each week ("high goal")

[3]As each condition had a single group of five users, the terms "condition" and "group" are used interchangeably in this chapter.

	High Goal	Low Goal
High Red Threshold	A1 5 Users	A2 5 Users
Low Red Threshold	A3 5 Users	A4 5 Users

Figure 4.21: Individual conditions

and have a red threshold (the point where sedentary activity turns the individual light red) of 5% below their average ("high red threshold"). Users in the second group (condition A2) would receive goals 5% above their average activity levels each week ("low goal") and the same high red threshold. The third and fourth groups (conditions A3 and A4) would have high and low goals respectively, with both groups having a red threshold of 10% below their average activity levels ("low red threshold"). (Figure 4.21)

I defined a further four conditions that focussed on evaluating the group display. Users in the first two groups (conditions A5 and A6) would receive both the individual and group displays simultaneously. For these users, the middle light on their devices would change colour to show their individual activity, and the ranking lights would activate and deactivate (appearing to change position) to show their ranking against other group members. Rankings for users receiving condition A5 would be calculated over a sliding window of seven days ("long ranking time"), while rankings for users receiving condition A6 would be calculated over a sliding window of three hours ("short ranking time"). Individual performance would be calculated using a high goal and low red threshold (the same as for condition A3).

Users in the next two groups (conditions A7 and A8) would receive only the group display, with users receiving condition A7 having a long ranking time and users re-

	Long Ranking Time	Short Ranking Time
Individual and Group Visualisations	A5 5 Users	A6 5 Users
Group Visualisation Only	A7 5 Users	A8 5 Users

Figure 4.22: Group conditions

ceiving condition A8 having a short ranking time. Users receiving these conditions would not see an individual activity light (rather, they would see their static identifying colour), and would only be able to gauge their performance by seeing their ranking against others in the group. (Figures 4.22 and 4.23)

I considered that, to qualitatively evaluate as many design variations as possible, it was desirable to have as many conditions as possible. In contrast, in order to generate quantitative results through statistical analysis, it was desirable to maximise the sample size in each condition, necessitating assigning a larger number of users to a smaller number of conditions. Given my focus on qualitative evaluation (discussed in Chapter 3), I decided on the former, thus the use of eight conditions. Once I had determined which display variations worked well, I could then evaluate the best variants in a future study with a larger user cohort to collect significant quantitative results.

I decided that a study duration of six weeks would allow participants sufficient time to use Activthings in their full range of daily activities, and allow them to receive several different weekly goals.

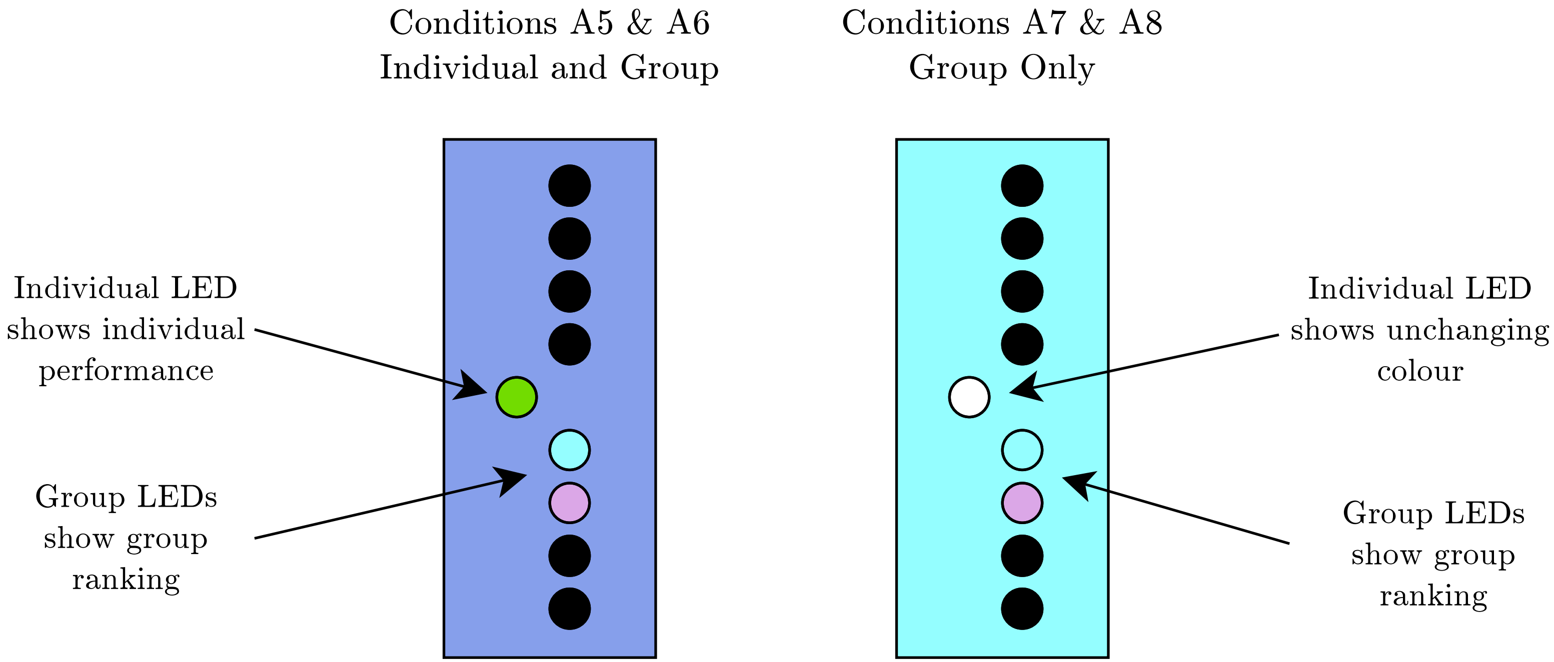


Figure 4.23: Example of combined (A5, A6) and group-only (A7, A8) conditions

4.2.10 Recruitment

I defined the following inclusion criteria for the study:

- Living in Australia.
- Ages 18 to 65 (inclusive).
- Not engaging in a minimum of 30 minutes of moderate-intensity physical activity on most or all days of the week.
- Have a desire to increase physical activity over current levels.
- Have a mobile phone compatible with the Activthings device.

I defined the following exclusion criteria:

- An injury, disability or other factor that would prevent regular engagement in moderate-intensity physical activity.
- Life events that could affect physical activity levels, such as surgery, travel, or a change of work or study.

I required prospective participants to be resident in Australia for the duration of the study. The Activthings device would need to connect to the Internet regularly and participants' phones might not work, or they might incur large data charges, while out of the country. Analysis of the data collected from the devices would also be complicated if users were in significantly different time zones. This would also negatively impact on the effectiveness of the group display, where it is preferable that participants are using their devices simultaneously.

The age range of 18-65 aligned with the Australian Government's "Physical Activity Guidelines for Adults" (Department of Health, 2005), on which the physical activity threshold—30 minutes of moderate-intensity activity on most or all days—was based. Some of the instruments I intended to use in the evaluation process, such as the IPAQ, had also not been validated with persons outside of the 18–65 age range. Allowing children to join the study would have complicated the consent process and introduced additional ethical concerns.

The requirements of activity falling below the *Guidelines*, and intention to be more active, was to ensure participants' goals were aligned with the intent of the Activthings device—to assist people to become more active rather than maintaining an existing adequate level of activity. The goal stretching aspect of Activthings was designed for the former and not the latter.

The exclusion of prospective participants with a relevant injury or disability was to ensure that participants would not have any encumbrance to increasing their level of physical activity. Similarly, I wished to exclude participants who anticipated a change of lifestyle that might artificially increase or decrease their ability to engage in physical activity, to avoid biasing the study results.

In contrast to the Activmon study, I expected users would connect their personal mobile phones to the Activthings device for the duration of the study. Therefore, it was necessary to ensure participants had a compatible mobile phone—one with Bluetooth, supporting one of the PAN, DUN or SPP protocols, and enabled for mobile Internet access. In practice this meant people with an Android- or iOS-based smartphone. It would have been possible to recruit users who owned "feature phones", but I considered the inevitable technical difficulties of supporting dozens of feature phone systems would have been unnecessarily frustrating, both for me and the participants involved.

Inevitably in a study where participants are required to have certain hardware, there will be some selection bias. Although there are now more mobile phone services in Australia than there are people, there will always be a small number of people who don't own or use a mobile phone. Whilst smartphone penetration in Australia is extremely high and many people have mobile data included in their phone plan (84% of respondents according to a 2013 survey by Mackay (2013)), there is still a significant number of people who do not own a smartphone or have access to mobile data.

This is of particular concern considering I have argued for Activthings being a device that is potentially particularly accessible to people in lower socio-economic groups. People in these groups tend to lack access to the latest technologies enjoyed by more affluent members of society. Unfortunately it was impractical, given the resources I had available to complete my research, to offer participants a phone to use in the study if they didn't already have a compatible phone. Whilst it in no way invalidates the results of the study, I feel it is important to acknowledge this bias up front.

I recruited participants through a variety of different channels. I placed paid advertising for the study on Facebook and Google. I was interviewed on a state-wide radio program and appeared in a prominent position in a state-wide Sunday newspaper. The University of Tasmania promoted my study on the home page of their website. I also put out an appeal for participants on Twitter. I personally invited people to join the study, some of whom I knew and others who I didn't know. However, the vast majority of prospective participants had no prior contact with me or knowledge of my research prior to joining the study.

I directed prospective participants to a website where they could read the participant information, consent to be involved, provide their name and contact details, and answer a series of eligibility questions (as per the eligibility criteria described earlier—copies provided in Appendix Section D.2.1). They were asked to enter their date of birth and were not permitted to proceed if they were currently under 18 years old or over 65 years old. They were asked to confirm that their phone had Bluetooth capability and that it had Internet access, and were not permitted to proceed if they answered "no" or "unsure". Prospective participants were also asked if they had any disabilities or injuries that would prevent them from doing regular moderate-intensity exercise. If they answered "yes" or "unsure", they were not permitted to proceed with the sign-up process and were instructed to consult

Stage	Number Completed
Completed consent form	149
Completed "initial questions"	137
Completed "personal information"	125
Completed "current activity"	123
Completed "activity inventory" (IPAQ)	121

Table 4.1: Number completing each sign-up stage

with their doctor.

I asked prospective participants to complete a series of questions on their physical activity behaviour and intentions—whether they felt they were doing enough exercise, whether they wanted to do more exercise in the future, and whether they anticipated any significant life changes that would affect their level of physical activity. I also asked them to complete the short-form International Physical Activity Questionnaire (IPAQ) (Booth et al., 2003) to obtain a quantitative measure of their current activity levels.

After I had recruited a sufficient number of people I closed sign-ups. Of a total of 149 people who commenced the sign-up process (people who consented to participate), 121 successfully completed sign-up (passed preliminary eligibility questions, provided personal details and activity information and completed the short-form IPAQ). Twelve people dropped out at the preliminary screening page and a further twelve when asked to enter personal details (such as name and address). Only four then failed to complete the activity questions and IPAQ. Members of the public showed a strong interest in becoming involved in the study and the retention rate through the sign-up process was good. (Table 4.1)

The following statistics include only the 121 prospective participants who completed the entire sign-up process.

A total of 96 prospective participants (80%) identified themselves as women with the remaining 25 (20%) identifying as men (Figure 4.24). They were offered the opportunity to indicate multiple or alternative gender identities, however, none did.

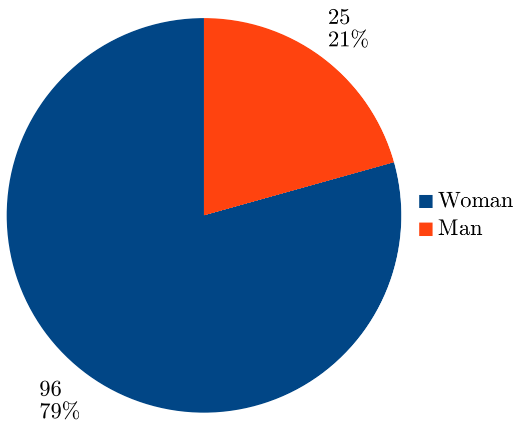


Figure 4.24: Gender Identity

Prospective participants spanned the eligible range, with the youngest prospective participants being 18 and the oldest 65 (Figure 4.25).

Almost all prospective participants (106, 88%) reported having a mobile phone that was on a plan as opposed to pre-paid. Over 90% (100) had a phone that I determined to be compatible with the Activthings device. These were split fairly evenly between iPhones (53%) and Android-based phones (47%), with most Android-based devices running version 4 of the operating system (“Ice Cream Sandwich”) or above. (Figure 4.26)

I scored prospective participants’ IPAQ responses according to the IPAQ scoring protocol. Around two thirds (68%) placed in the “low” and “medium” activity categories, where “medium” is approximately equivalent to the Australian Guidelines of 30 minutes of moderate-intensity activity five days a week. The remaining participants placed in the “high” category, exceeding this guideline. I excluded one participant because their responses to IPAQ questions were too high (perhaps due to misunderstanding the questions). (Figure 4.27)

Expressed in terms of Metabolic Equivalent of Task (MET), the Australian Physical Activity Guidelines equate to around 500 MET minutes per week. That is, 30 minutes of 3.3 MET activity on five days of the week. Of all prospective participants, only 22 reported doing less than 500 MET min/wk. A total of 44 reported less

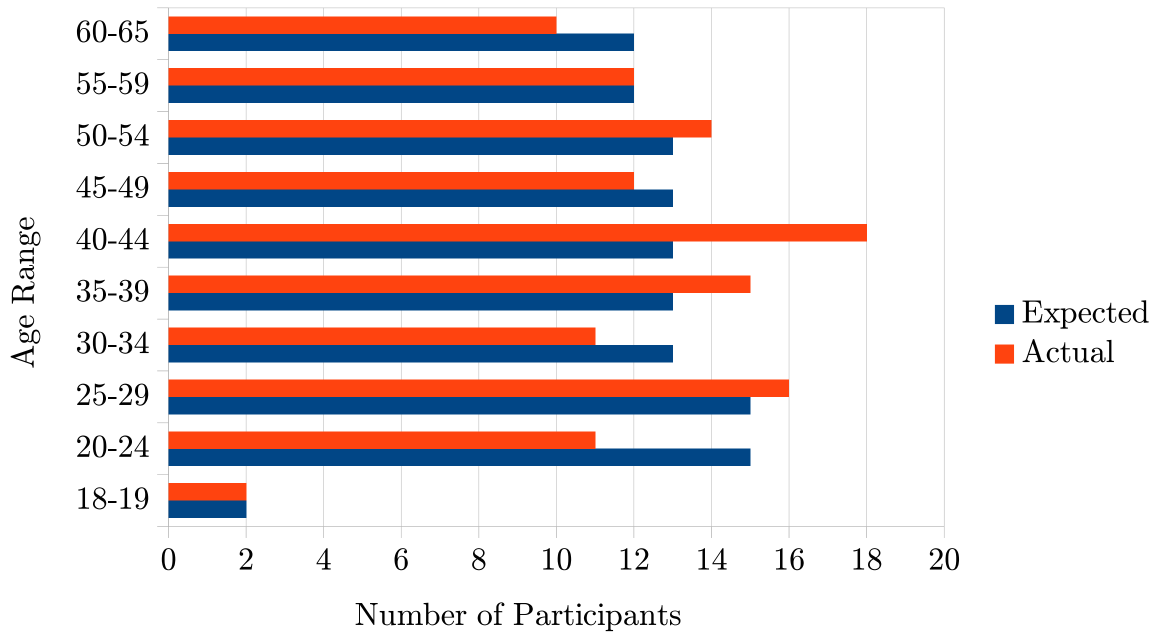


Figure 4.25: Actual number of participants in each age range compared to expected participants if the same number were drawn from the general Tasmanian population

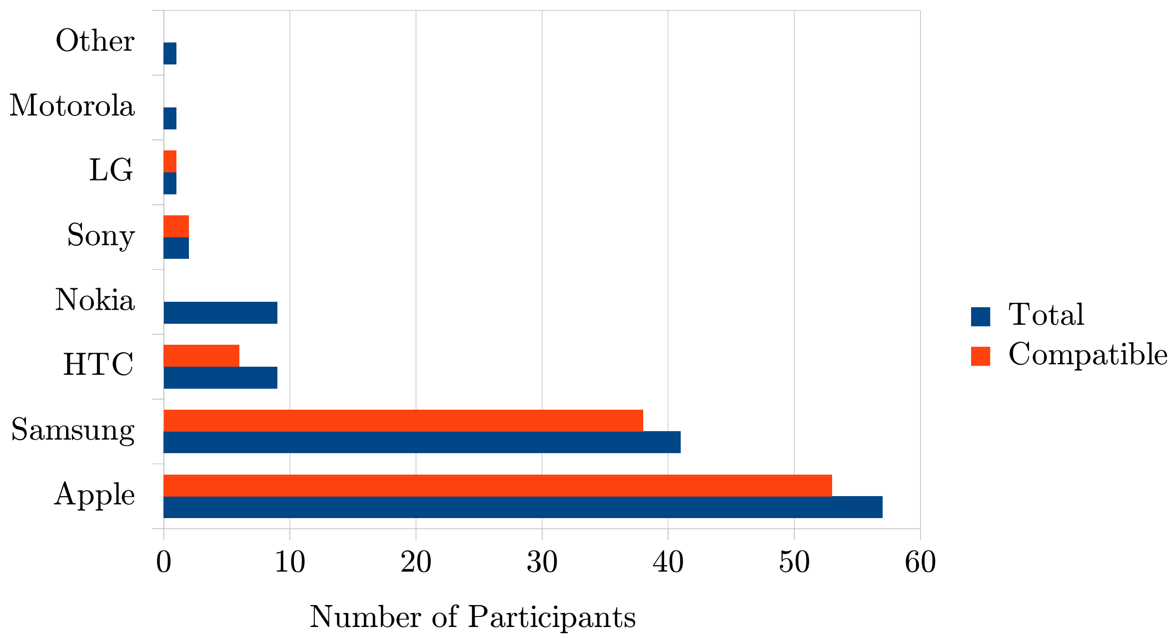


Figure 4.26: Compatibility of prospective participants' phones by brand

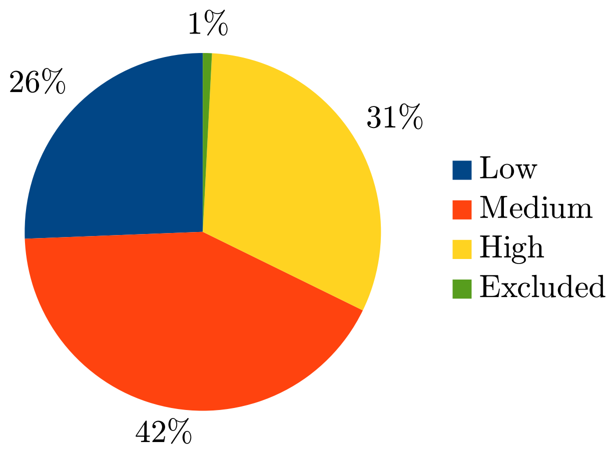


Figure 4.27: Prospective participants' IPAQ categories

than 1,000 MET min/wk (37%) while 76 (63%) reported greater than 1,000 MET min/wk activity. The IPAQ scoring guidelines tend to classify even people with over 2,000 MET min/wk activity as having "medium" activity as respondents are asked to report on all lifestyle activity, not the more restrictive "leisure time physical activity" (LTPA) used in formulating public health guidelines. The IPAQ is also biased toward participation, tending to score a participant who is active on more days higher than one who is active on less days, even though they may have a similar total MET min/wk (IPAQ Group, 2005).

I asked prospective participants the questions, "How active are you now?" and, "How active do you want to be in the future?", as a point of comparison with their IPAQ responses. In general, users' answers aligned with their IPAQ category and number of MET minutes per week.

In response to "How active are you now?", 80% of prospective participants in the "low" IPAQ category said they needed to do "somewhat more" or "a lot more". This reduced to around 60% for the "medium" category, and just 30% for "high". (Figure 4.29) Most prospective participants reporting less than 1,000 MET min/wk activity answered, "somewhat more" or, "a lot more", reducing to around a half to a third in the range 1,000–2,000 MET min/wk. Those reporting 2,000 MET min/wk or more were far more likely to categorise their current activity levels as "about

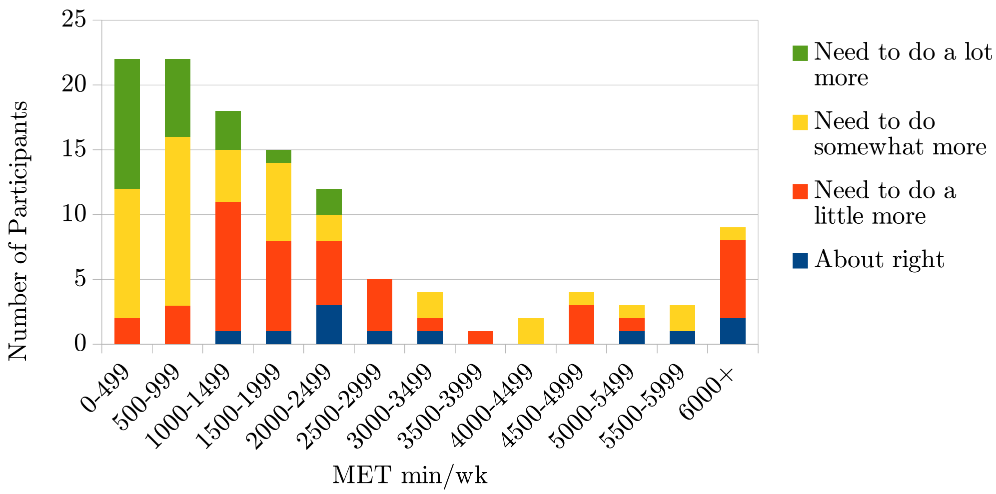


Figure 4.28: Current activity by IPAQ MET minutes/week

right" or "need to do a little more". (Figure 4.28)

When asked, "How active do you want to be in the future?", the relationship between future intentions and current activity was less pronounced. Prospective participants overwhelmingly responded that they wanted to do "somewhat more" or "a lot more" activity, with even 70% in the "high" category responding as such. Only in the high category did anyone respond they wanted to do "about the same [level of activity] as now". (Figures 4.30 and 4.31)

The distribution of ages of prospective participants matched that of the wider Tasmanian population (Australian Bureau of Statistics, 2010), across the ten age groups that matched the study age range. There was, however, a significant imbalance toward men. Perhaps it was the case that women are more engaged with physical activity monitoring than men, or that the particular form factor employed (a bracelet) was more appealing to women. (Table 4.2)

More prospective participants were on mobile phone plans, as opposed to prepaid arrangements, than would be expected of the wider Australian population. Smartphone ownership, however, was not significantly different from the Australian average at the time of the study. (Table 4.2) (Mackay, 2013)

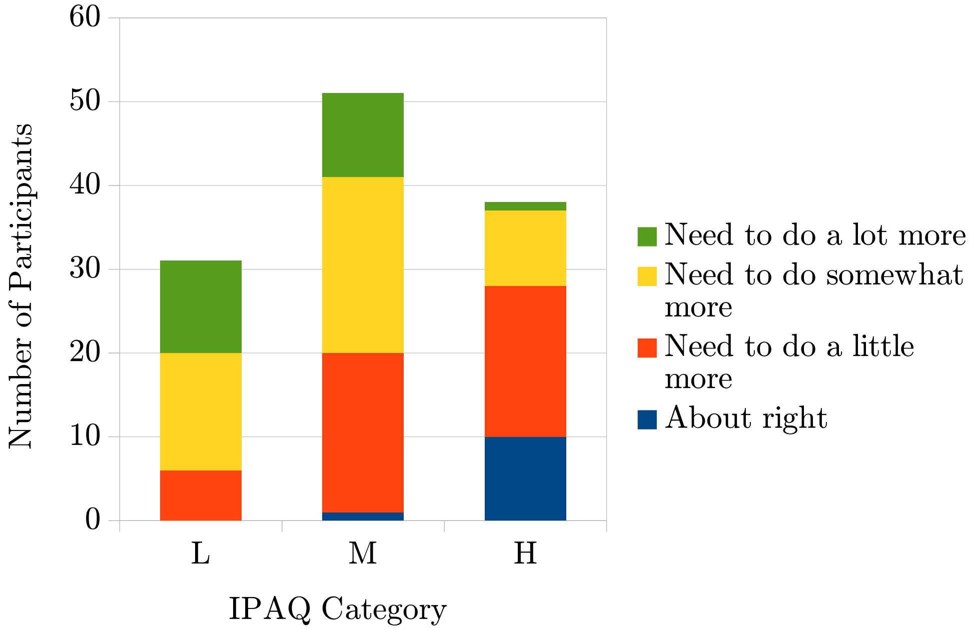


Figure 4.29: Current activity by IPAQ category

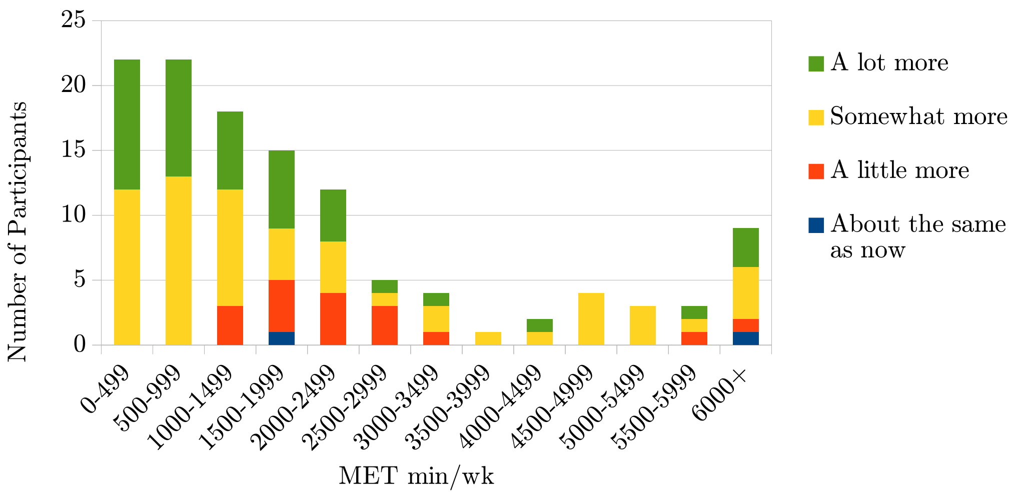


Figure 4.30: Activity intentions by IPAQ MET minutes/week

Dimension	*df*	*N*	χ^2	*p*
Age	9	121	5.87	.75
Gender identity	1	121	41.66	$< .01^{**}$
Use of mobile plan	1	121	5.40	$.02^{*}$
Smartphone ownership	1	121	0.18	.67

Table 4.2: Tests for goodness of fit of the prospective participant population with the wider population

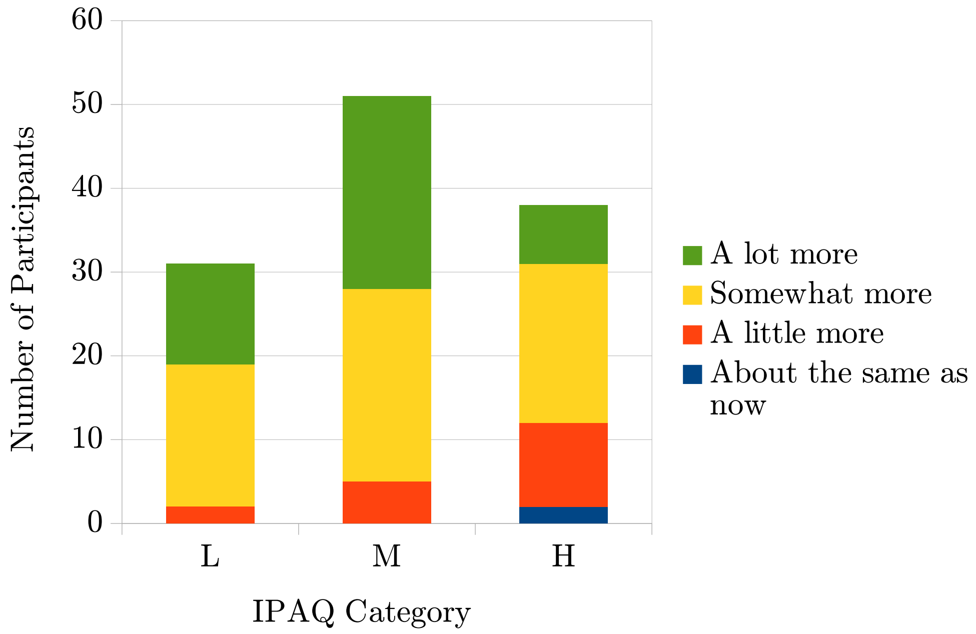


Figure 4.31: Activity intentions by IPAQ category

Despite my offer to reimburse participants for reasonable out-of-pocket expenses it is likely that some people with prepaid phones decided not to participate for fear of high data charges. The bias toward plans may also have reflected the large number of people recruited through the University staff newsletter and website. It could be argued that staff and those connected to the University belonged to a more affluent socio-economic group, and would be less likely to own prepaid mobile phones.

The apparent relationship between prospective participants' activity beliefs and IPAQ categories and MET min/wk scores suggests their beliefs were consistent with their actual self-reported activity levels. The relatively high MET scores are likely explained by a focus in the IPAQ questions on whole-of-life activity rather than just leisure-time physical activity (LTPA). The weaker relationship between current activity and future desired activity is to be expected—the study would have naturally attracted people with a desire to do more regardless of current activity levels. Those people with a weak desire to improve their activity levels would likely not have chosen to enrol.

There was something of a bulge of respondents reporting 4,000 MET min/wk or above, and the relationship between activity perceptions and intentions and MET seems weak in this region. Whilst some of these respondents may have been accurately reporting an unusually high level of activity, I feel it is more likely that they simply misunderstood the IPAQ questions. A high level of activity would be recorded, for example, if a respondent reported their weekly activity levels in a question asking specifically for activity over a typical day. This problem could have been due in part to the design of the web-based IPAQ forms presented to prospective participants—they were given sliders that could be set to improbable values such as 18 hours of intense physical activity in a single day.

4.2.11 Selection

After closing sign-ups, I proceeded to undertake a second level eligibility evaluation, in line with the participation criteria and exclusions outlined in Section 4.2.10. I eliminated prospective participants who indicated that their current activity level was "about right" or that in the future they wanted to be "about the same as now" in terms of activity. These prospective participants did not meet the eligibility criteria of wanting to increase their level of activity or wanting to increase it. Whilst people's self-report could be inaccurate, I saw little value in providing people who were comfortable with their current level of physical activity with an intervention intended to increase it.

I wrote a computer program[4] to score prospective participants' short-form IPAQ responses, following the procedures in the "Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire—Short Form and Long Form", November 2005 edition (IPAQ Group, 2005). I eliminated any prospective participants who fitted the "high" category as defined by the Guidelines—approximately equal to one hour a day or more of moderate-intensity activity above

[4] Available from the author on request

the basal level of activity. These prospective participants did not meet the eligibility criteria of being less active than the Australian Government physical activity *Guidelines*, equivalent to half an hour of moderate-intensity physical activity on most or all days (Department of Health, 2005).

I considered eliminating prospective participants who fell into the "medium" category as well, as the Guidelines defined this category as approximate to "half an hour of at least moderate intensity PA on most days", which is equivalent to the Australian Government *Guidelines*. There was the question, however, of exactly how comparable this IPAQ category was to the Government recommendation, given inclusion in the IPAQ of leisure-time physical activity. I therefore decided to admit these prospective participants if they had also indicated a belief they needed to be more active, and an intention to do more in the future.

I had asked participants to indicate whether they knew of any significant life event that would affect their ordinary level of physical activity. For example, travel overseas, leaving an existing job or starting a new one, taking up a new course of study or finishing/graduating from an existing one, or going into hospital for surgery. This was to assess the eligibility requirement that participants not have any planned life events that would artificially increase or decrease their physical activity. I excluded five prospective participants who reported expecting such life events.

I started inviting the remaining 68 eligible prospective participants, in groups of ten, to complete a questionnaire designed to evaluate their self-efficacy for exercise regulation in different circumstances (copy provided in Appendix Section D.2.2). For example, when they were recovering from an illness, when they were busy at work, or when they had family staying over. I used the example proposed by Bandura in his book chapter "Guide for Constructing Self Efficacy Scales" (Bandura, 2006), as validated by Everett, Salamonson, and Davidson (2009). One prospective participant withdrew at this stage and several others did not respond to the invitation emails. In these cases I continued to send invitations to others until ten had completed the questionnaire and agreed to participate further.

I assigned five of the initial ten respondents to the first individual activity group (A1) and five to the second group (A2). I sent each of them an Activthings device, charging cradle, USB cable and USB charger by mail. I also included a short instruction sheet directing them to watch a YouTube video explaining how to wear, charge and operate the Activthings device and what feedback to expect during the study (`https://www.youtube.com/watch?v=0flceJg6YBE`). I provided an offer of phone and email technical support to answer questions regarding the device and the study.

I continued to invite eligible prospective participants in groups of ten to complete the self-efficacy questionnaire. Each time ten had completed the questionnaire, I divided them into two groups of five and assigned them to the next two empty groups. I continued this process until a total of 40 participants had commenced, five to each condition.

Of the original 40 participants who commenced the study and were sent an Activthings device, five never returned any data. Of those five, two had technical issues where the device never worked with their phones, one withdrew shortly after the study started, and two kept their devices to the end of the study but never wore them. Of those who wore the devices and collected data, five withdrew before the end of the study, one of these due to an intermittent technical fault.

I was concerned that, for the group conditions, missing participants would impact on the experience of remaining participants. Therefore I recruited two additional people to fill two of the three positions that had been vacated by participants who withdrew without collecting any data. Neither of these replacement participants subsequently withdrew. I decided not to replace participants who had worn the device and collected data, as I was concerned that this would bias participation statistics toward showing higher participant retention than was actually the case.

What attracted you to sign up to our research study?	
Reach fitness goals/be more active	15
Interested in study/results/device	10
Be motivated/encouraged	8
To help out/like to participate in research	7
Interested in knowing/seeing own activity levels	4
Lose weight	2

Table 4.3: Participants' motivations to join the user study

What were you hoping to get out of your participation in the study?	
Get fitter/be more active	16
Motivation/inspiration	9
Help out with research/interested in study	8
Information about own activity levels	7
Weight loss	2

Table 4.4: Participants' expectations of the user study

4.2.12 Motivation for Participating

In a questionnaire I asked selected participants to, in their own words, discuss what attracted them to sign up to and participate in the study, and what they hoped to get out of it. I analysed participants' responses and extracted common themes. I then tallied the number of times each theme was mentioned. The results are shown in Tables 4.3 and 4.4. (Note that some participants may have discussed multiple themes in a single response.)

Most participants were attracted to the study due to a desire to become more fit, more active in general or to reach their own fitness and activity goals:

> "I love fitness and the possibility of participating in something that might help me lose my last few kgs or pushing me to reach my next fitness goal" *A119/A1*[5]

[5]Each quote is appended with the participant's unique, anonymous identification code and the condition they received (A1–A8).

> “I am interested in increasing my level of physical activity, and saw this as an opportunity to assist me with that goal” *A311/A5*

> “I thought it would help me get more active” *A425/A4*

Many were simply interested in trying out the Activthings device or being part of a research study:

> “I wanted to increase my activity and also wanted to help someone’s research” *A769/A7*

> “[I] wanted to assist the research” *A993/A5*

Less prevalent yet still common themes were wanting to be motivated or encouraged as a result of wearing Activthings, or gaining a greater understanding of one’s own activity levels:

> “I need to lose weight but with my family and study commitments, couldn’t join a gym and was unaware of how much exercise I was actually doing” *A152/A3*

> “I liked the idea of participating in a study that would monitor my activity and I was interested to see if having my level of activity displayed on my wrist would act as an incentive to exercise more” *A808/A8*

> “I needed to exercise more for my health and I thought the Activthing [*sic*] would encourage me to exercise more” *A385/A7*

Some participants said the device itself, either the ambient display or the fact that it was 3D printed, attracted them to sign up:

> “[I liked] innovation [and] use of 3D printing” *A513/A1*

> “I liked the idea of using lights as indicators rather than just figures with most other devices” *A903/A3*

> “[I was] interested in my reaction to the light changing colour” *A734/A4*

Only two participants stated an explicit intention to lose weight.

4.2.13 Summary

From analysing prospective participant sign-ups, it was possible to make a number of observations. It was encouraging to see that there was a great degree of interest in the Activthings device and study, with 121 prospective participants signing up over the space of two weeks after only a moderate amount of advertising. More people would have signed up had I not closed the website. Recruitment can be a challenge but it would seem that, at this time, it is not difficult to find participants for studies involving physical activity and wearable computers. I would therefore not expect recruitment to be difficult when there is the need to attract more participants for future studies of this nature.

Prospective participants were motivated more by the desire to become or stay fit rather than weight loss. This was a realistic goal for most, whose IPAQ scores placed them below the recommendations in the Australian Government physical activity guidelines. It was good to see that less active people were encouraged to become involved, rather than only those who were already active. In order for the

Activthings approach to realise health benefits it is necessary to attract this group, and this will be important for future long-term studies.

Also encouraging was the interest in Activthings and the user study from people of a broad range of ages. The distribution of ages was a good fit for the age distribution of the population overall, indicating that the wearable computing approach is broadly inviting and not attractive only to younger people with greater exposure to new technologies. This removes one possible source of bias and presents a greater number of prospective participants.

The significant interest of women over men, however, was concerning as it limited my ability to determine whether there might be a gender-linked response to the Activthings device and activity displays. For example, it could be that there is some men's equivalent of Consolvo's finding regarding wearable devices and women's clothing (Consolvo et al., 2006). The lack of interest from men also limits the overall pool of prospective participants.

The need to recruit people with phones that were compatible with Activthings resulted in an unavoidable bias toward people of a higher socioeconomic status. Promotion through University channels would have also contributed to this bias. It would be interesting in future to be able to assess whether ambient displays are more accessible to people with a lower level of health, and overall, literacy. This would require a different recruitment strategy to specifically target those of low socioeconomic status.

Having users select themselves into the study was the simplest and most practical sampling strategy, but it would have introduced some bias. People who saw images or video, or who read descriptions, of the Activthings device and did not like it would not have signed up, leaving those who found the device interesting or attractive.

Chapter 5

Results and Discussion

In the previous chapter I introduced the design for Activthings—a wearable ambient display device incorporating individual and group physical activity displays. I discussed the structure of a user study, to be conducted with 40 users over six weeks, to evaluate Activthings.

I collected qualitative and quantitative data using a variety of methods:

- Likert items and free-form questionnaire responses
- Activity data collected directly from users' devices
- Pre- and post-study International Physical Activity Questionnaire (IPAQ) responses, and
- Pre- and post-study self-efficacy questionnaire responses

I have provided copies of all questionnaire items in Appendix Section D.2.3).

In this chapter I discuss the results of that study, with reference to the evaluation criteria outlined in Section 3.2.

	High Goal	Low Goal	
High Red Threshold	A1 5 Users	A2 5 Users	10 Users
Low Red Threshold	A3 5 Users	A4 5 Users	10 Users
	10 Users	10 Users	

Figure 5.1: Collapsing of individual conditions

5.1 Grouping of Study Conditions

In Section 4.2.9 I defined eight different study conditions and assigned five users to each. In the first four conditions (A1–A4) I provided users with variations of the individual activity displays. In the other four conditions (A5–A8) I provided users with variations of the group activity display, with users in conditions A5 and A6 receiving both the individual and group displays in combination.

In the following analysis I discuss the experiences and performance of the cohort as a whole and also of users in particular conditions. In Section 4.2.9, I discussed the decision to prefer a larger number of smaller groups, in order to evaluate as many display variants as possible. As a simple method to derive meaningful quantitative results for particular analyses, I collapsed some conditions on a common variable. Individual conditions A1 and A2 collapse to produce a group of ten users who all received a high red threshold. A3 and A4 collapse to a group of ten who received a low red threshold. Users in conditions A1 and A3 received a high goal and users in conditions A2 and A4 received a low goal. (Figure 5.1)

Group conditions A5 and A6 collapse to create a group of ten users who received

	Long Ranking Time	Short Ranking Time	
Individual and Group Visualisations	A5 5 Users	A6 5 Users	10 Users
Group Visualisation Only	A7 5 Users	A8 5 Users	10 Users
	10 Users	10 Users	

Figure 5.2: Collapsing of group conditions

both individual and group displays. A7 and A8 collapse to create a group who received only the group display. Users in A5 and A7 had a long group ranking time and users in A6 and A8 had a short ranking time. (Figure 5.2)

A limitation of this approach is that it considers variables in each condition to be independent when in fact they may not be (i.e. the goal level and baseline level for each user may together affect motivation). This limitation must be considered when interpreting results that appear to show a preference to one construction or another. However, given a focus on qualitative results there is still value in analysing the collapsed groups.

5.2 Information Presentation

In Section 3.2 I defined three evaluation criteria in the category of Information Presentation. The first related to comprehension—whether users reported understanding of the information presented. The second related to accuracy—whether users perceived the display to be accurate compared to their actual physical activity. Lastly, explicit social persuasion—whether the display managed to engage users in conversations with others around them about physical activity, whilst respecting the wearer and their environment.

5.2.1 Comprehension and Accuracy

The question of whether users comprehended the information presented could relate to face-value comprehension, or whether users derived any significant meaning from the information. I was confident that users understood the individual and group activity displays on face-value—I had provided all users with a comprehensive video explaining the operation of the device that covered the meaning of the individual display (red was bad, green was good) and the group display (it shows a ranking and you are in the middle).

In terms of whether users derived any deeper meaning from this information, this question is closely tied to the second criterion—accuracy. The intention of both displays was to enhance users' awareness of their own activity levels. If the user had difficulty deriving meaning from the information presented, or the information presented was inaccurate, this would be clear from subjective measures of perceived accuracy. For this reason I consider these two criteria together.

Individual Display

I asked users who received the individual activity display (conditions A1–A6, $N = 27$) to answer a series of questions about whether they understood the display and thought it was accurate. Although users in conditions A5 and A6 received the group display in combination with the individual display, I asked them to focus specifically on the individual light when answering these questions.

When presented with the statement, "I could understand how active I was by looking at the light", 44% of users who received the individual display agreed, although 37% were neutral. 41% disagreed with the statement, "The light was inaccurate compared to my actual activity", with 26% indicating they were neutral. To the statement, “The light didn’t tell me enough about my activity levels”, 41% agreed, with 26% neutral.(Figure 5.3)

There were a number of trends in these responses based on users’ study condition (which determined the levels at which their individual activity light turned red or green). Participants who had a low goal (105% of their sliding window average activity) ($N = 9$) were more likely to report that the individual light was accurate, compared with participants who received a high goal (110% of average) ($N = 10$). Users who had a high red threshold (95% of their sliding window average activity) ($N = 9$) were more likely to report that the individual light didn’t tell them enough, compared with those that received a low red threshold (90% of average) ($N = 10$). (Figure 5.4)

Users who received a low goal and low red threshold (condition A4, $N = 5$) were more likely to respond that they could understand how active they were, that the light was accurate and that the light told them enough, than users in any other condition.

Users’ long-form responses revealed they were split on the question of accuracy and comprehension:

> “I liked the challenge of making it go green but it wasn’t clear how much i [*sic*] needed to do to make that happen.” *A61/A2*

> “The lights on the device were able to reflect the goal, however they were largely uninformative” *A311/A5*

I asked users who had received the individual activity display (conditions A1–A6, $N = 27$) how satisfied they were with their automatically-generated goals, and whether they reached a point where they couldn’t be, or didn’t want to be, more active to reach them (a “ceiling”). This could indicate the goals were too high or

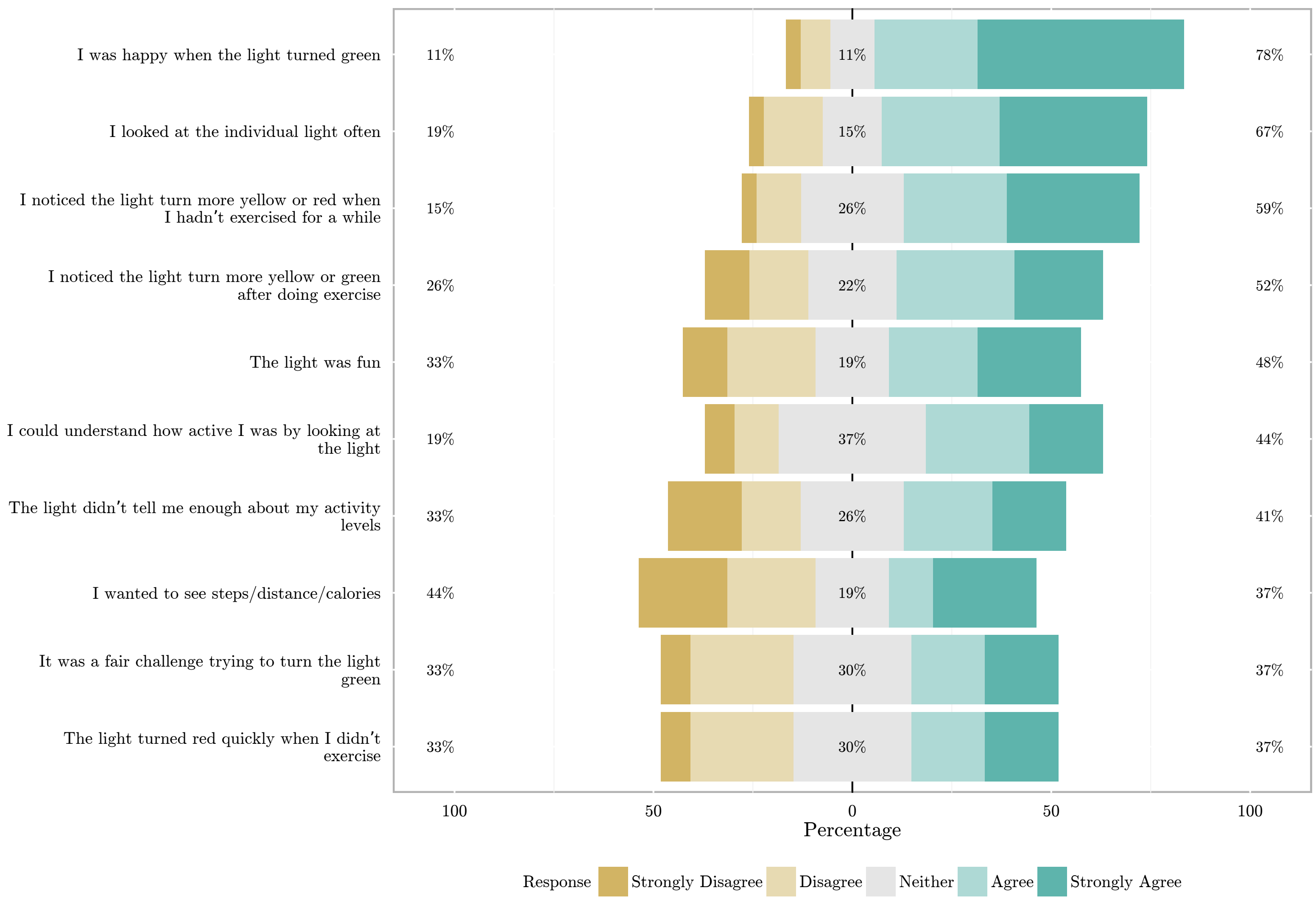


Figure 5.3: Responses to individual display questions (percentages represent combined Strongly Disagree and Disagree, Neutral, and combined Agree and Strongly Agree)

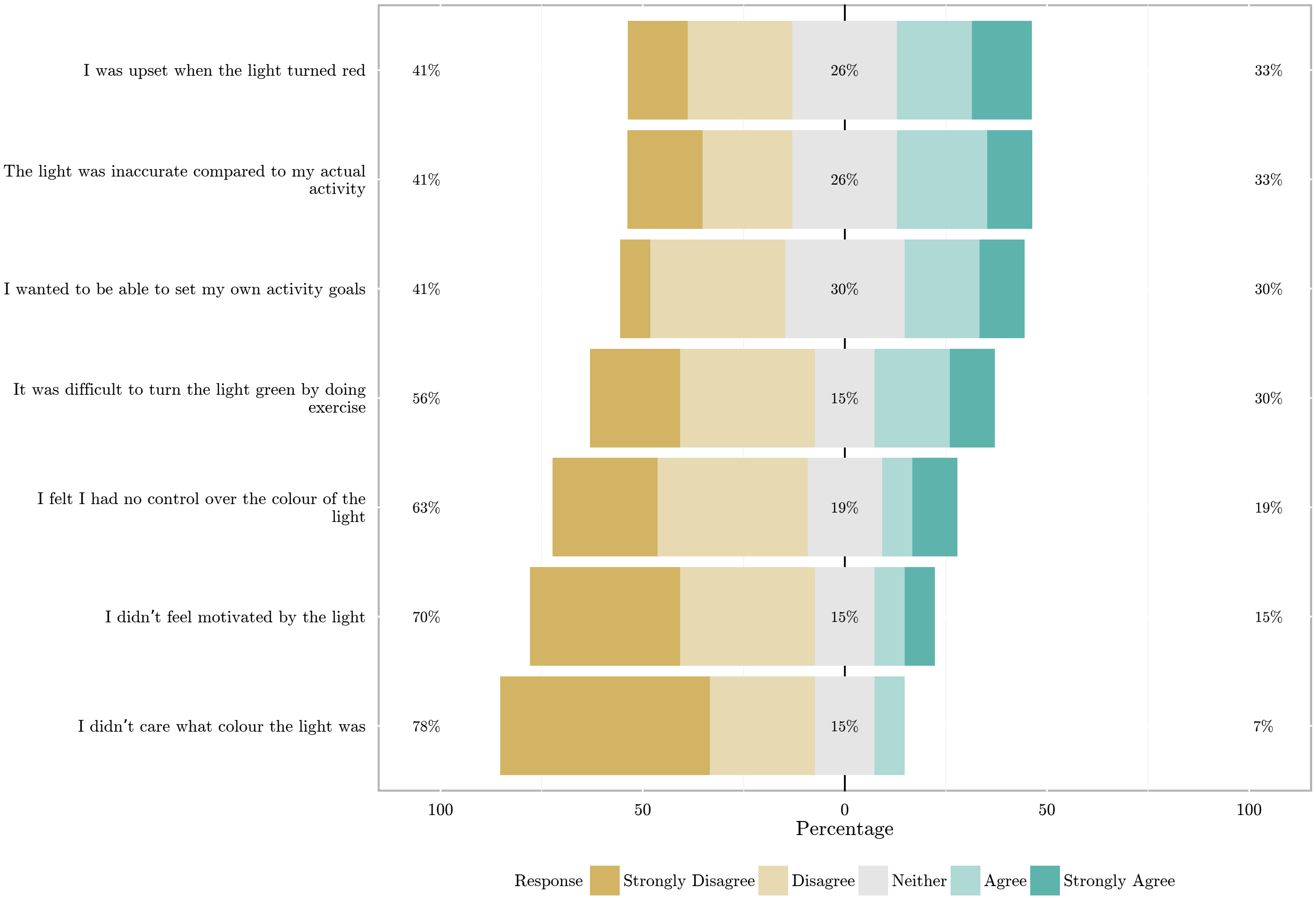


Figure 5.3: Responses to individual display questions

increased too quickly, or that they were too low and too easily achieved.

Of the 26 participants who responded, 11 reported they reached this goal “ceiling” and 15 reported they hadn’t. Seven users reported their goals were “too hard”, 15, “about right”, and four, “too easy”. No participants reported their goals were “much too hard” or “much too easy”. Of the seven who felt their goals were too hard, five reported reaching a ceiling. Of the 15 who felt their goals were “about right”, five said they reached a ceiling. Of the four who felt their goals were too easy, only one said they reached a ceiling. There did not appear to be a connection between a participant’s condition and goal satisfaction or perceptions of having reached a ceiling.

Informally, a number of participants said they felt their initial goal (created using the first three days of data) was inaccurate. The goal was either too easy (in which case the light stayed green for most of the following week) or too hard (where the light was difficult to turn green).

Participants did not express a strong preference to have control over their goals, with more users saying they didn’t want to set their own goals (41%), or not caring (30%), than users who expressed a desire to do so (30%).

To users who received the individual display ($N = 27$) I posed the statement “I wanted to see steps/distance/calories”, to which responses were reasonably evenly split between 37% who agreed and 44% who disagreed. Users’ preference for this type of information did not appear to be associated with their study condition.

The question posed to users about whether they felt they had reached a goal “ceiling” was ambiguous—users’ responses could have meant that they found the goals so difficult they couldn’t reach them, or that the goals were of a level where they didn’t want to reach them. It’s understandable that users who were dissatisfied with the difficulty of their goals didn’t feel motivated to achieve them. Interestingly though, one third of users who said their goals were “about right”, and even one user who

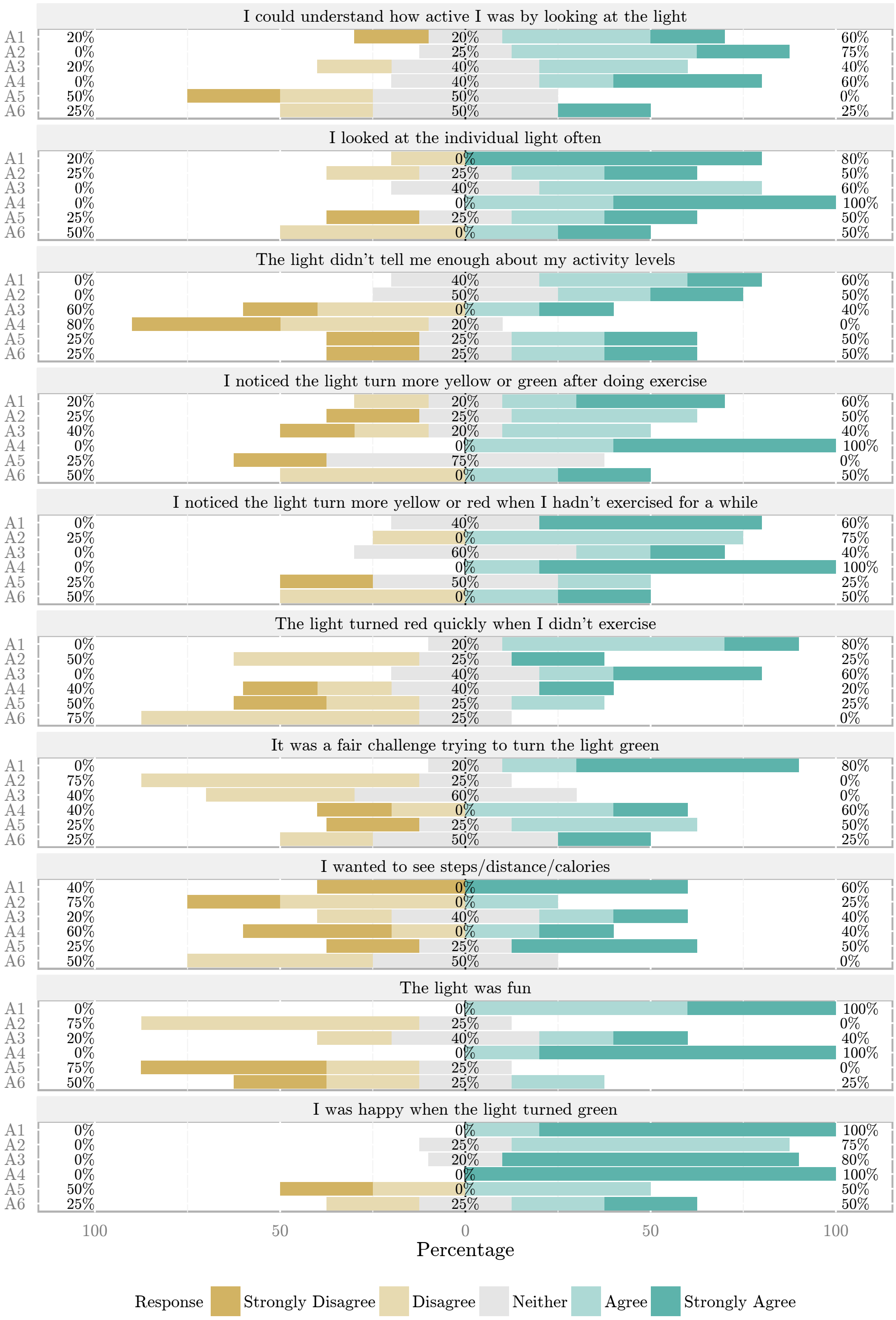


Figure 5.4: Responses to individual display questions by condition

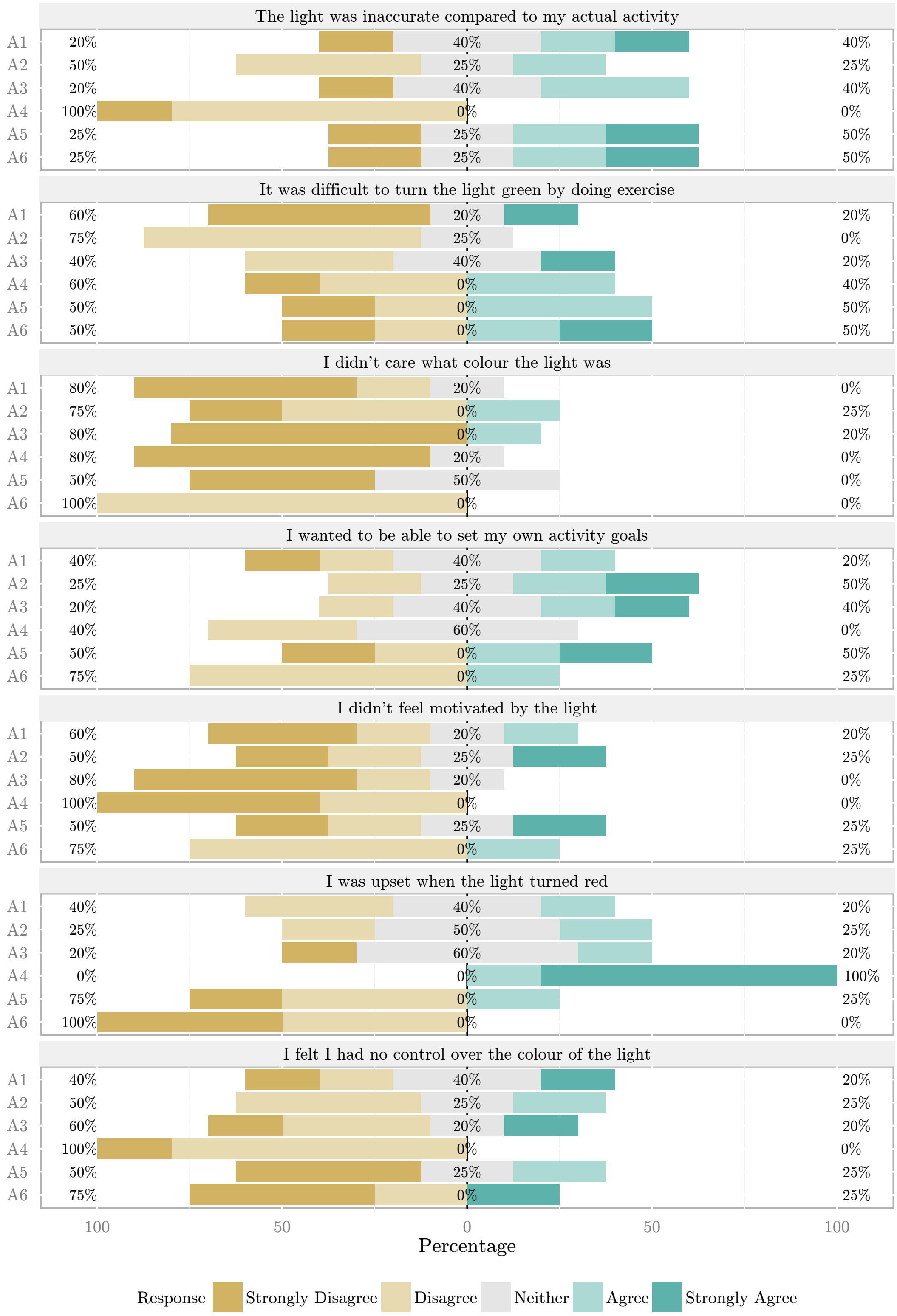


Figure 5.4: Responses to individual display questions by condition

felt their goal was “too easy”, said they didn’t want to or couldn’t achieve a goal. This may mean that their goals were generally reasonable but that the device was ineffective at motivating these users.

The intention of creating a goal quickly (with only three days of data) was to avoid leaving users with a blank device for a whole week, however, the resulting inaccurate goals may have in fact harmed users’ trust in the device and made them less likely to wear it.

Downward goal adjustment also seemed to be a problem, judging from graphs of participants’ activity against weekly generated goals (see Section 5.4). The purpose of this adjustment was to avoid participants’ devices staying red constantly—if the participant had received a goal that was too high, or if they had to reduce their activity levels for some reason, the next goal should be automatically lowered to be just above their new weekly average activity level. This would provide participants with a more achievable goal and, it was hoped, encourage them to remain engaged with the display.

Ultimately, however, this seems to have resulted in some users engaging in progressively less activity over the course of the study. If the light was red at the end of a week then, upon the next goal being generated, it would change to be more yellow (in line with the new goal matching the user’s current weekly average). For some users there was a notable oscillation, where goals would increase and decrease cyclically due to alternating upward and downward goal adjustment. This may have provided the unintentional feedback to participants that their performance against previous weeks’ goals had improved, when in fact it hadn’t.

In light of a clear variance in all preferences relating to goals, it may be better for users of such a device to have some control over their goals. This could be as simple as an interface allowing users to indicate the current goal is “too high”, “too low” or “about right”, with the system learning to adjust accordingly (Burns et al., 2011).

I concluded that the preference for a more complex display was likely specific to each individual. For users who had been previously exposed to activity monitors employing high-complexity displays it might have simply been a preference for data in a familiar form, rather than an ambient display which users would not have previously seen.

Overall, these results suggest that comprehension and perceived accuracy were linked to the difficulty of achieving a goal (the goal level) and the tolerance of the display for recidivism (the red threshold). If the goal was easier to achieve, users reported the display was accurate. If the display turned red too easily, users reported it didn't tell them enough about their activity levels.

Perhaps an easier goal aligned better with users' perceptions (right or wrong) that they were being active. A green light is a positive result that would have been well received whether it was deserved or not. A red light is a negative result that would prompt concern and questioning if the user felt it was undeserved, leading to perceptions of inaccuracy.

A display that turned red easily would tend to give less feedback during periods of inactivity than one which turned red more slowly. Once the user's average activity reached the red threshold the light would be completely red and remain that way while the average remained below that threshold. A lower red threshold increases the region over which the light can change through shades of orange toward red, providing more nuanced feedback. This could explain the dissatisfaction expressed by users receiving the display with a high red threshold.

The intention of this study was to test a low-complexity ambient display in isolation, although I acknowledged that users may have a preference for receiving more detailed information through a high-complexity display on a computer or smartphone.

Group Display

I asked users who received the group activity display (conditions A5–A8, $N = 14$) to answer a series of questions about whether it helped them understand their own and others' activity levels. The majority of users (57%) understood what the ranking display meant and half (50%) said their position accurately reflected their own activity level. 79% of users indicated the ranking display didn't tell them enough about how active other people were. (Figure 5.5)

Concurrency within groups was important for the group display to be effective. The more users there were in a group who were wearing the device at the same time the better the display for all of them, as more people would appear in the ranking. If a user hadn't worn their device for more than 24 hours, they would be removed from the group display of all other users in that group.

Concurrency within most groups was good, with users seeing one or two other lights, apart from their own, on most occasions. Group A7 appeared to operate best, with three of the four users seeing at least two other lights most of the time. This may have been due to the fact that two users in this group wore the device for a significant number of hours over the study and were therefore likely to be using their devices when others in the group were.

Across the other groups four users saw no other lights for a significant proportion of the time they wore the device. This may have been a result of those users starting the study earlier or finishing later than others in their group. For the users in group A8, poor concurrency was the result of their group having only two active users.

As could be expected, comments from users in group A8 were negative:

> "[I disliked] the days when, even after a run, there was no feedback at all"
> *A988/A8*

Only rarely would a user have seen three other lights (representing three other users wearing their devices), and at no time did any user see four other lights active (which would have represented every user in the group having worn their devices within the past 24 hours). (Figure 5.7)

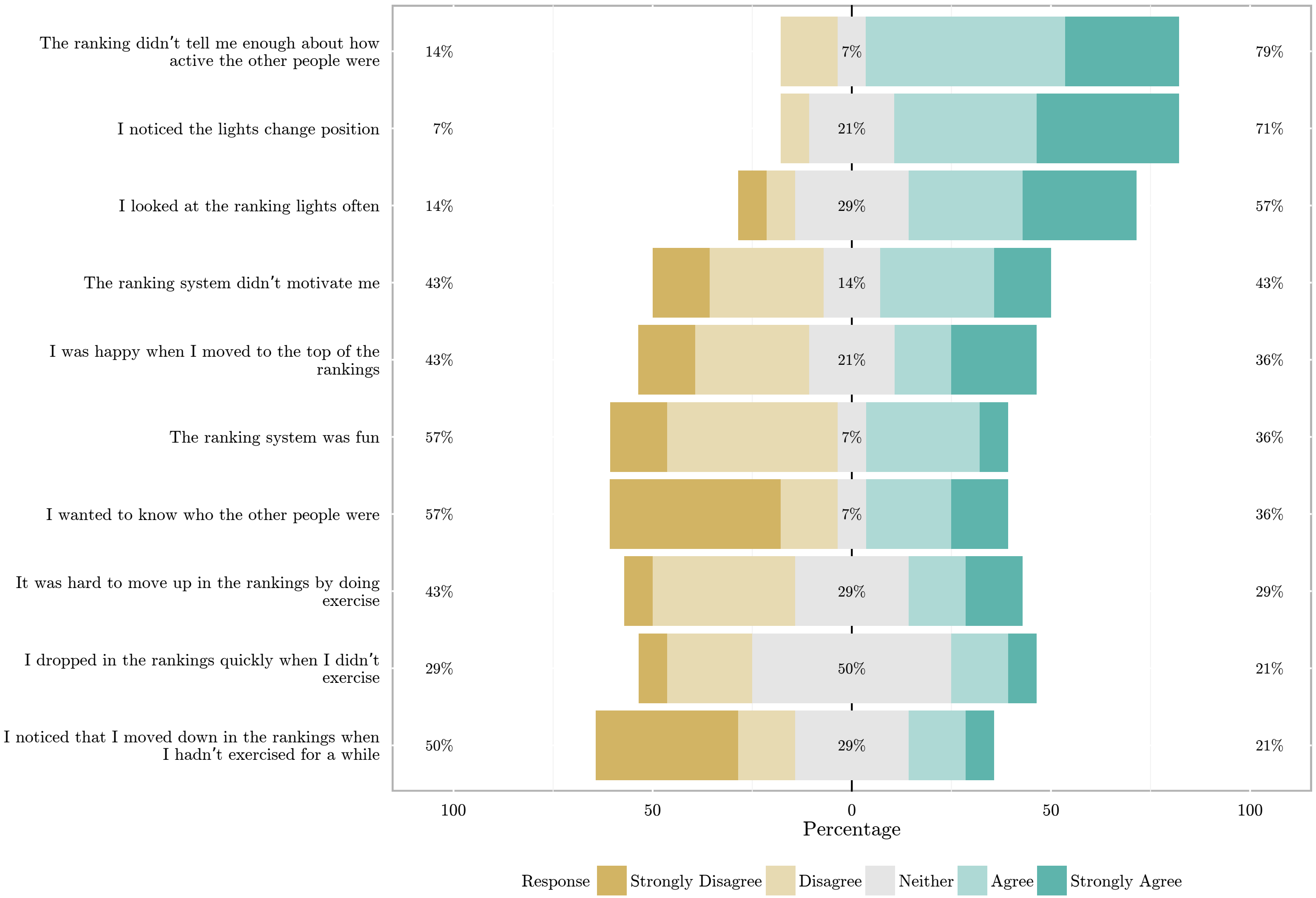


Figure 5.5: Responses to group display questions

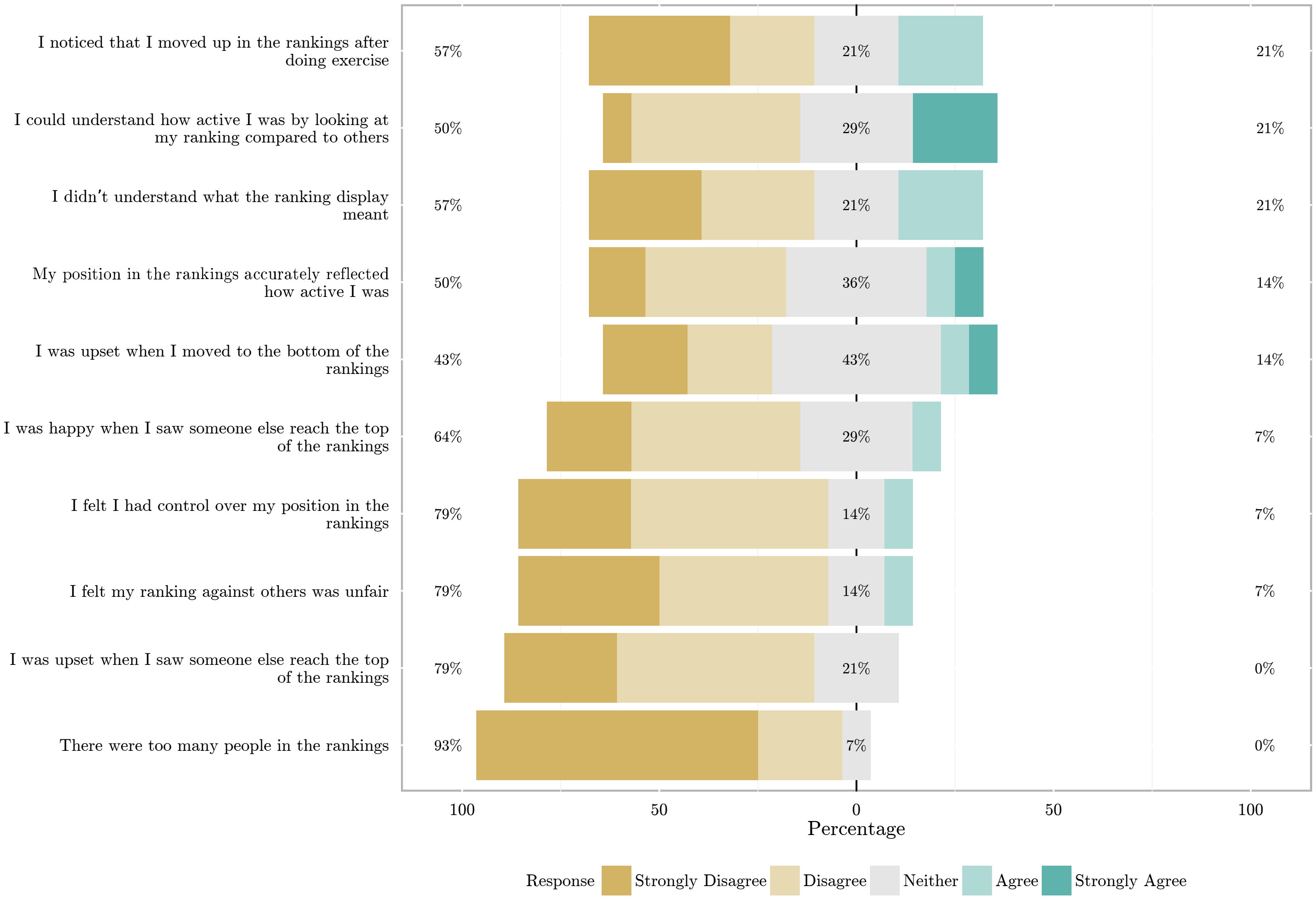


Figure 5.5: Responses to group display questions

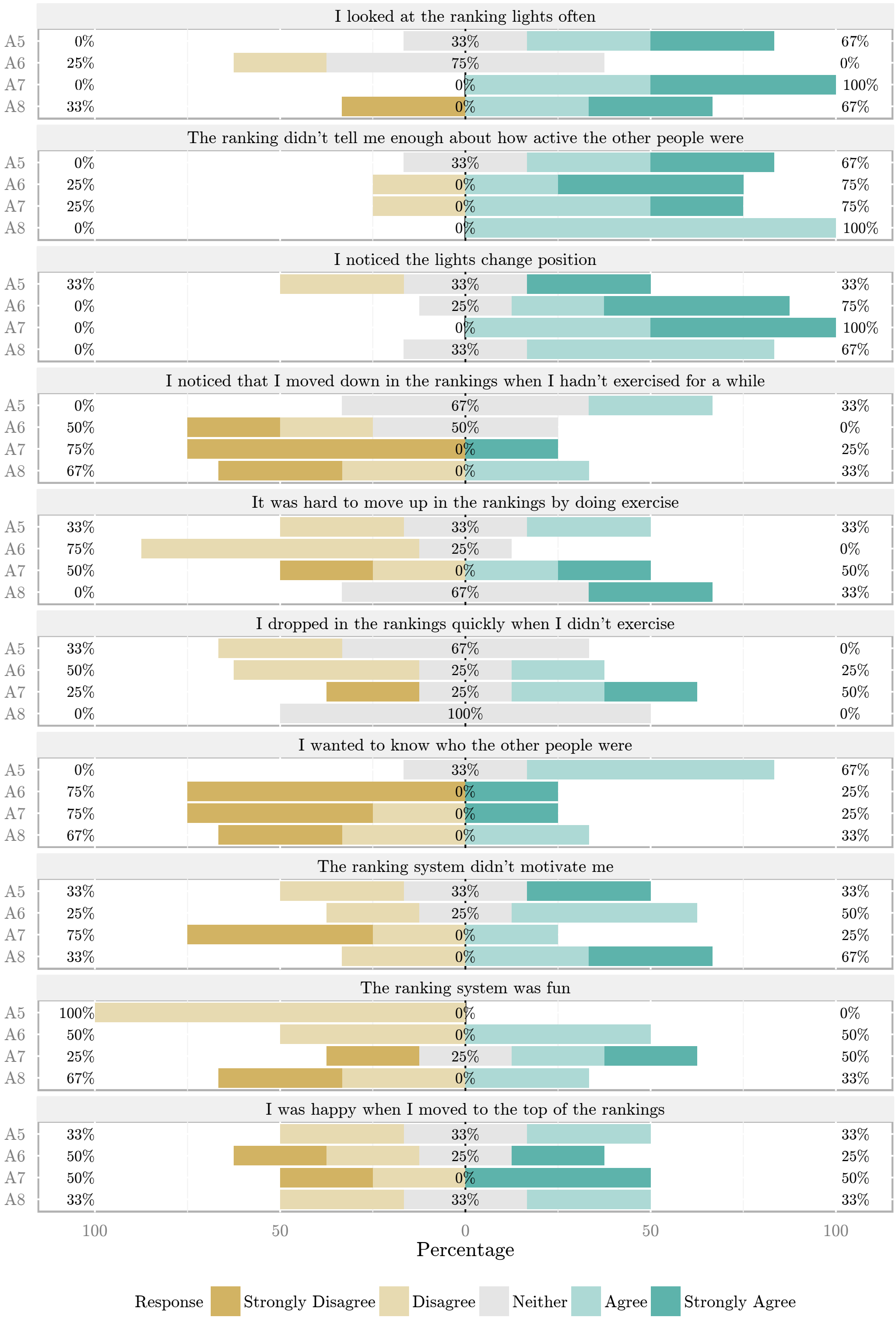


Figure 5.6: Responses to group display questions by condition

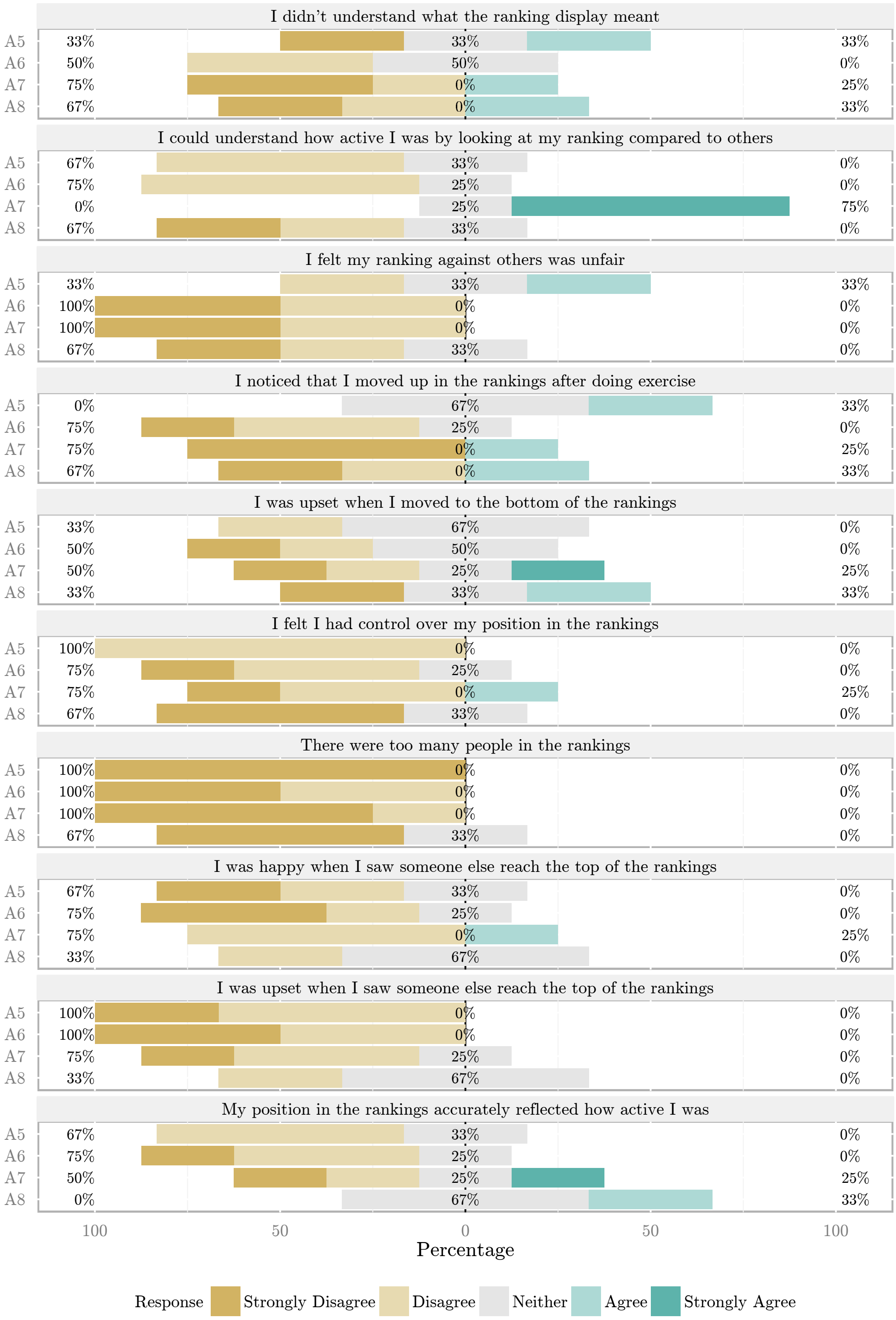


Figure 5.6: Responses to group display questions by condition

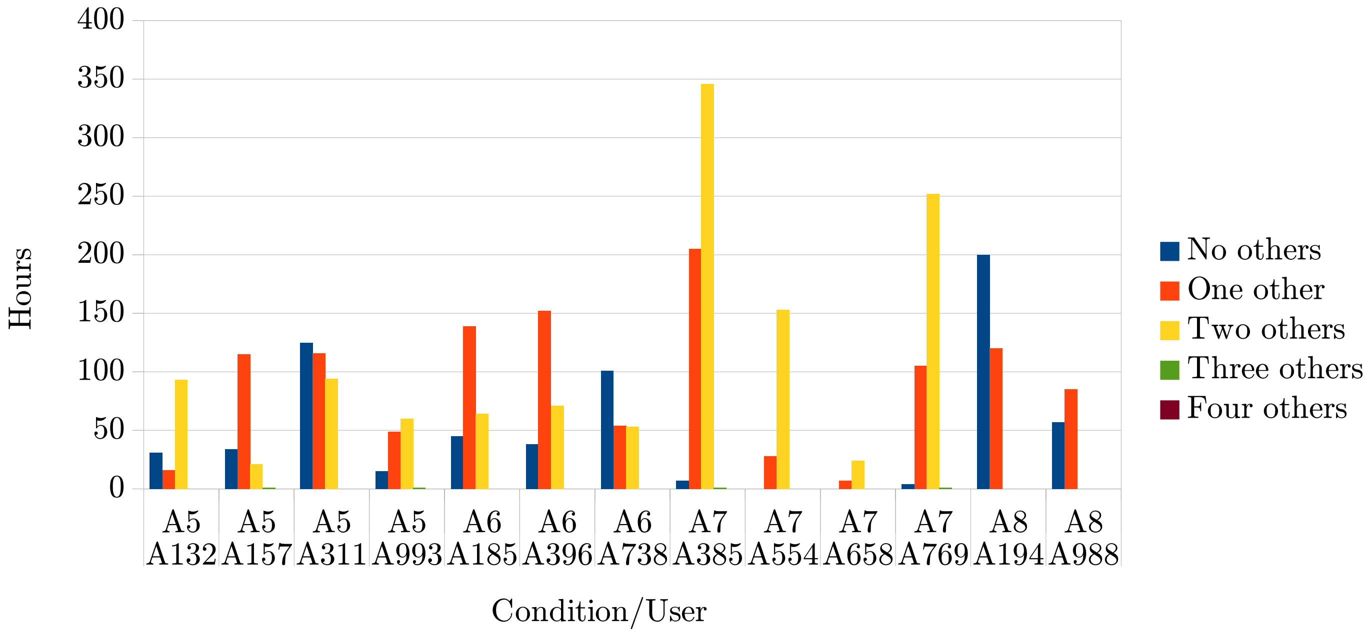


Figure 5.7: Concurrency for users in group conditions

For most users, the most frequent rank they received within their group was first. With the exception of two users, third was an uncommon rank to receive. No users ever saw themselves ranked fourth or fifth. This was primarily due to low concurrency within groups—a user would see themselves as first whenever all other users in their group had timed out of the display. Higher concurrency would likely result in a better distribution of ranks for each user.

Condition A7 ($N = 4$) was noticeably unbalanced, with one user mostly ranked first, another mostly second and another mostly third. On analysing individual users' data, however, this result appeared fair and was not a failure or artefact of the ranking system. It may nonetheless have been demotivating to be in second or third place too often. (Figure 5.8)

Users in group A7, where there was the highest concurrent use, responded more strongly to the statement "I could understand how active I was by looking at my ranking compared to others" than users in any other group. This appears to confirm my theory that higher concurrency produces a more meaningful display. Unfortunately though users in this group, and all other groups, responded negatively on questions of comprehension of the group display and perceived accuracy.

Scepticism about the group display may have been in part due to the anonymous nature of the information provided. Users may have distrusted information they could not independently verify and therefore perceived accuracy to be poor. It may be better to study the group interface with a number of people who already know each other, such that users can see the real-world activity of those in the group and how this is reflected in the rankings.

Other advantages are that the group interface could leverage pre-existing social dynamics, increasing the likelihood that participants would wear the device concurrently and respond to the indications provided. This would also be more representative of how I intended the group display would operate in the real world (with participants having different coloured devices to reinforce the coloured light-

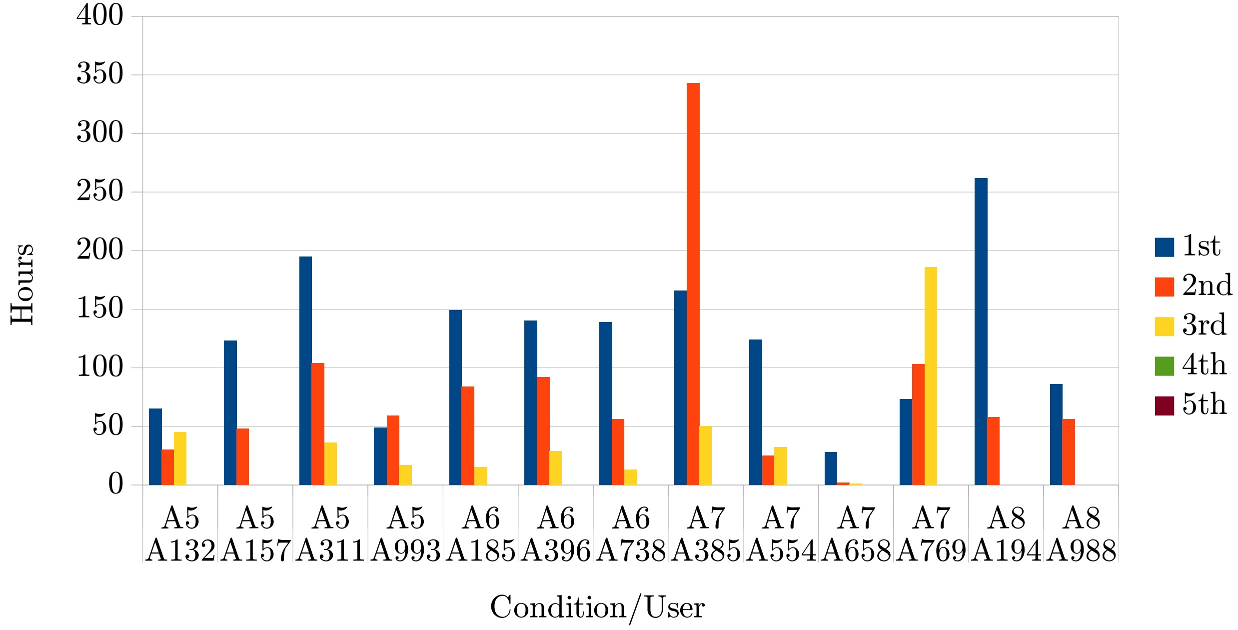


Figure 5.8: Ranks for users in group conditions

to-person mapping).

I was concerned, however, that these very effects would tend to bias the study outcomes, making it difficult to distinguish between an increase in monitoring and/or physical activity caused by social factors or an increase caused by the device itself. I had hoped that social behaviour might have emerged despite participants being anonymous, however most users (57%) reported not wanting to know who the other users were, and fewer reported an emotional response to their ranking changing.

At least one user was concerned that they were being compared directly with others rather than against their own activity:

> "I didn't understand whether the other people (other lights) were being ranked according to their performance against their own average activity, or against mine" *A769/A7*

In future it would be important to more clearly explain the basis on which rankings are calculated, in order to assure sedentary users that they have an equal chance of reaching the top of the ranking as an active user, provided they can reach their personal goals.

5.2.2 Explicit Social Persuasion

Users did not indicate a strong desire for their displays or the meaning behind the displays to be private. Whilst users expressed concern about wearing Activthings in some situations where the device might be offensive to others for aesthetic or social reasons (discussed in Section 5.3), the highly visible nature of the device was a mainly positive characteristic, motivating users to monitor their own activity and prompting discussion with others.

Of users answering the post-study questionnaire ($N = 34$), 91% indicated that people noticed that they were wearing the device. However, only 11% indicated they felt that it prompted awkward questions or that (outside of specific situations where it was socially inappropriate) they were embarrassed to wear it.

> "The device certainly stimulated lots of discussions with people I met and maybe got them thinking about exercise. It also made me think about my activity a lot more than usual." *A769/A7*

Some participants went as far as saying they enjoyed the attention, joking about the "jail bracelet" aspect of the device and commenting that it looked "cool" and high-tech:

> "Surprisingly, I loved the attention I got from people wanting to know what it was. I loved being able to tell them what it was, what it was for, or joking occasionally that 'my parole officer was making me wear it' haha! I also enjoyed the fact that my kids chimed in when the colour was anything but green. It definitely got noticed!" *A119/A1*

> "It was an interesting point for discussion with others, some wanting to know if I was under house arrest, others wanting to know if the device could help them" *A714/A1*

> "I felt very cool wearing it, like I was part of an experiment" *A513/A1*

This effect is the same as that postulated by Lim et al. (2011) in their evaluation of Pediluma—that eye-catching wearables could provide a benefit to the user through engaging them with others in discussions around healthy behaviour. Rather than being something undesirable that should be designed out, this property is actually a key motivational aspect of these displays. Obviously though, there is a balance between creating an ambient display that is likely to be noticed and creating one that is too intrusive, and a small number of participants felt the light(s) were too bright and/or were not appropriate in certain situations (discussed in Section 5.3). Context-awareness is a central theme in contemporary ubiquitous computing research and it would be interesting to explore ways of making Activthings more context-aware (such as dimming or switching off the lights based on the user's location).

5.2.3 Summary

Against the information presentation evaluation criteria, I showed that users were able to comprehend both the individual and group activity displays. Users appeared to have a preference for the individual display with a low red line and low goal, although given there were only five users in this condition this difference could have been due to chance. Automatic goal setting worked well although users' initial goals were inaccurate. Downward adjustment of goals was also a problem. It would be beneficial to provide users with some level of control over their goals, although this does not necessarily mean they need to be able to set them precisely.

A lack of concurrent wear and users leaving the study hampered the effectiveness of the group display, with users seeing few others on the display and receiving a first ranking too often. Anonymity may have meant that users didn't notice the activity of others in the group as much as they would if they knew them.

The highly visible nature of the wearable display device was a positive aspect, engaging users in discussions with others about physical activity. This finding of "explicit social persuasion" confirms the theory posed by Lim et al. (2011). Improved context awareness, or greater user control over the display, will nonetheless be important in future designs.

5.3 Design

I proposed two evaluation criteria relating to design—whether users found the size and appearance of the display device acceptable and whether the device was easy to use in real-world situations. Both of these criteria speak to the effectiveness of the device and displays in engaging the user with monitoring their physical activity. If the device is too large or awkward, or looks unattractive, users may not be willing to wear it. If the device is impractical or difficult to use this will present a practical barrier to engagement.

In the post-study questionnaire, I posed a series of long-response and Likert item questions to users relating to these usability criteria. (Figures 5.10 and 5.9)

I tried to make Activthings as small and attractive as possible, using surface-mount components and construction techniques and designing a custom 3D-printed plastic housing. This approach appears to have been successful in increasing user acceptance over the Activmon device, with half of all participants still using the device by the end of the study, and wear time increasing from an average of eight hours per day (in the previous study), to ten hours per day.

Whilst users still raised concerns about the size, appearance and usability of the device, these results indicate that the design of the device was nonetheless adequate to ensure that users would wear it, and therefore be able to regularly monitor their physical activity. They give confidence to the suitability of rapid prototyping technologies such as 3D printing in building and evaluating novel wearable interface designs. Researchers need not be limited to creating software and deploying it on commercially-available devices. Rather, they are now empowered to develop their own custom wearable research platforms.

One caveat is that, due to users self-selecting into the study, indications of user satisfaction will be positively biased. Future work could evaluate wearable ambient displays in the wider population in order to determine which subsets of users are

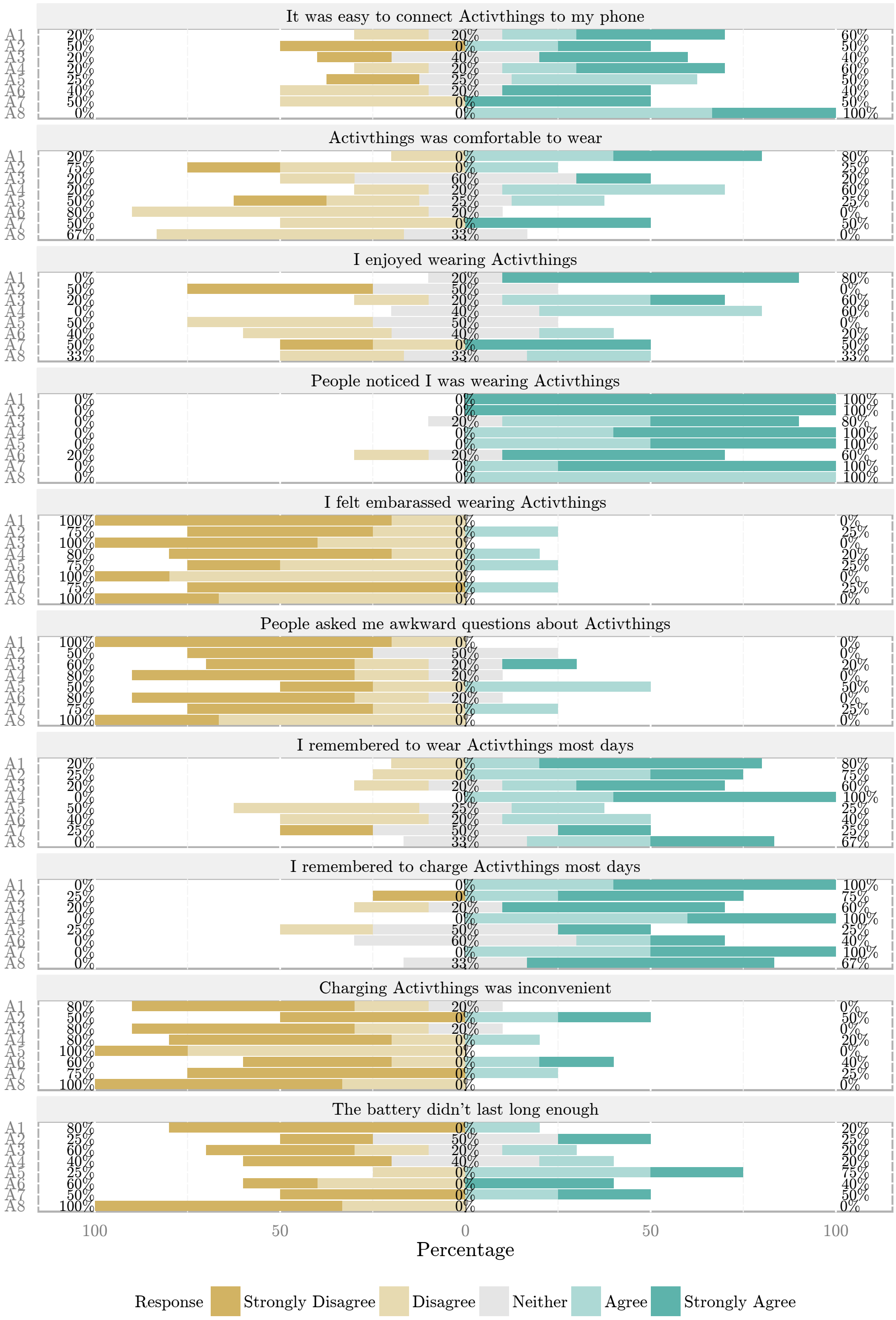


Figure 5.9: Responses to usability questions by condition

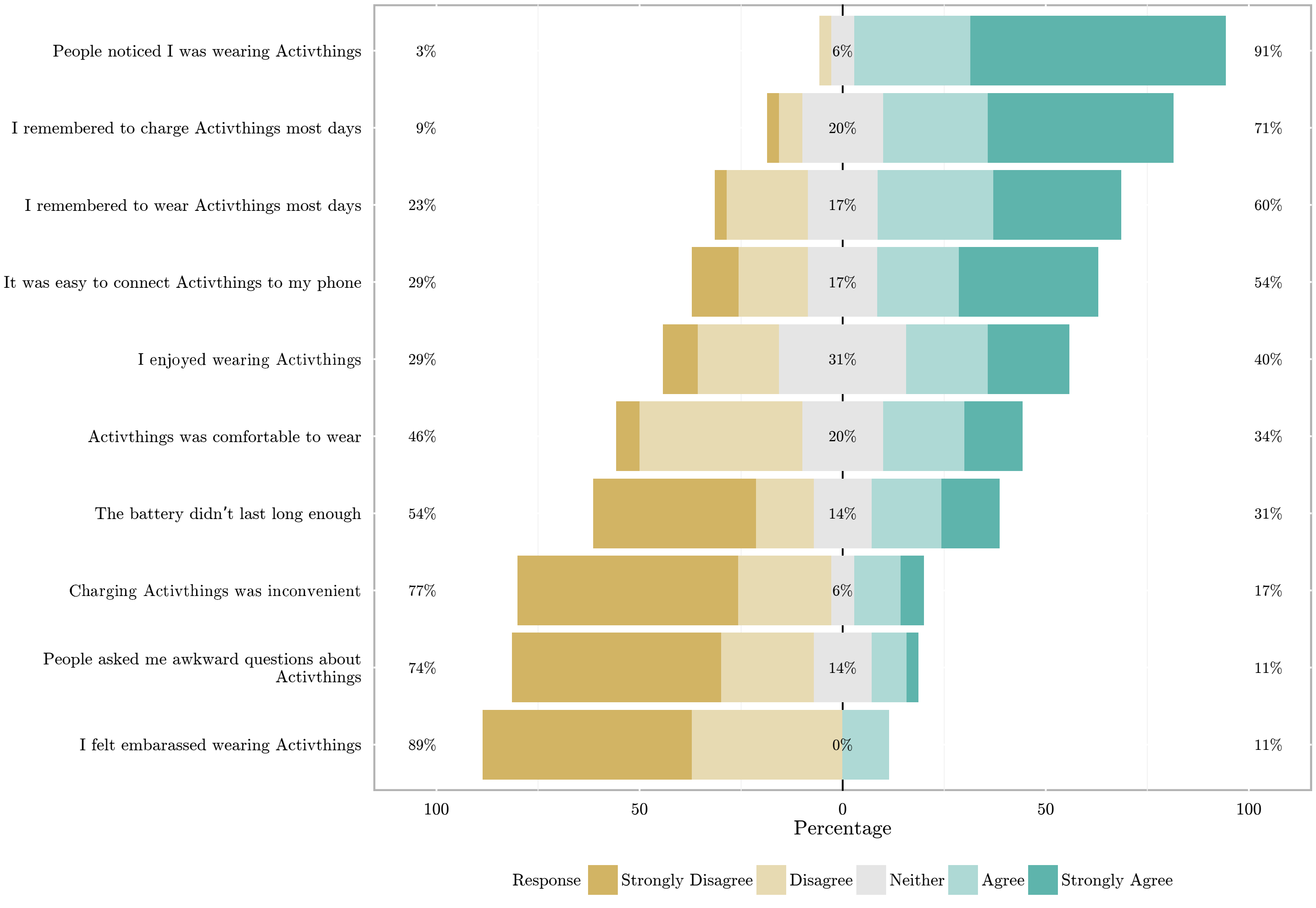


Figure 5.10: Responses to usability questions

more or less likely to accept it.

Activthings was designed and evaluated before the Apple Watch was released and at a time when wearable activity monitors (such as Fitbit) were only just gaining mainstream acceptance. Users were therefore not necessarily primed to prefer a wrist-worn form factor. I would expect that if the study were repeated users may have different expectations based on devices they have used previously.

5.3.1 Size and Appearance

Of users responding to the post-study questionnaire ($N = 34$), 34% agreed that Activthings was comfortable to wear, however a larger minority of 46% disagreed. In users' long-form responses, those who were dissatisfied commented that the device was too bulky, unattractive or that its appearance and form factor made it unsuitable to wear in certain situations.

> "It was a very bland device in terms of physical design and colouring" *A903/A3*

> "I didnt [*sic*] like wearing it as it was bulky and unattractive" *A132/A5*

> "I understand that the device was a prototype, however for everyday purposes the device was overly large, clumsy, and unattractive" *A311/A5*

Some users found the elastic wrist-strap in particular to be uncomfortable or ill fitting:

> "I didn't like that I couldn't make it fit tighter around my wrist until I sewed my own additional velcro [*sic*] strap onto it. I didn't like how bulky it is." *A119/A1*

What did you like least about the Activthings device, wearing the device and the study?	Times Mentioned
Bulky/unattractive/unfashionable/too bright	14
Wrist strap was a poor fit/uncomfortable	10
Inaccurate/uninformative/wanted more info/couldn't understand	9
Difficult or annoying to charge/poor battery life	6
Phone incompatibility/connection problems	5
Lifestyle incompatibility (sport/work/travel)	2

Table 5.1: Aspects participants disliked

> "The velcro [*sic*] was itchy to start with. It ended up catching on my clothes at times. I had to move my watch to the other wrist and made it a challenge to remember to look at the time there. However, having it on my wrist instead of my watch made me look at it and remember that I needed to keep exercising." *A512/A3*

> "It was a bit clunky and drew a fair bit of attention with 'what's that' type questions and the wrist strap broke/felt insecure" *A835/A4*

When asked about their least liked aspect of the device, 14 users said the device was bulky and unattractive and ten specifically mentioned the ill-fitting wristband. (Table 5.1)

Users in the study would have appreciated that the Activthings device was a prototype, intended to gather data for research purposes, and not a finished, commercial product. Acknowledging, however, that appearance would be an important concern for future devices, I wanted to better understand what users wanted out of a wearable ambient display.

I asked users to describe an Activthings device with the same lights and sensor but "improved" so that it could be sold in stores. I analysed their responses, extracted the main themes, and tallied the times each theme was mentioned (individual par-

Form Factor Theme	Times Mentioned
Slimmer/smaller	19
Fit smaller/different wrists, more adjustable/comfortable band	9
More/different information	9
Watch or something to tell the time	6
Different faces/colours/designs	4
More comfortable in general	3
More sturdy/durable	2
Waterproof	1

Table 5.2: Participants' suggested form factor changes/improvements

Form Factor	Times Mentioned
Wristband/bracelet	12
Digital watch	11
Analogue watch	3
Necklace	2
Shoe or shoe attachment	1
Item of clothing	0
Something else	3
Wouldn't want one	2

Table 5.3: Participants' preferred form factors

ticipants may have mentioned more than one theme) (Table 5.2). I also asked them which form factor they felt was most appropriate for this "improved" device, considering that some of them may prefer something significantly different than the bracelet form factor currently employed (Table 5.3).

An overriding theme was that participants wanted Activthings to be smaller and slimmer. Being able to tell the time was a common suggestion, although as many users would prefer the form factor to stay the same (a bracelet) as would like the display to be integrated into a watch. A shoe or shoe attachment (like Pediluma by Lim et al. (2011)) was the least preferred option, in line with the idea that users of a wearable ambient display would be interested in it being an appealing accessory that conforms to existing ideas of fashion.

Four participants specifically mentioned having different colours or designs, or interchangeable faces. Three wanted the device to be more comfortable in general, two felt it should be more sturdy, and one asked for it to be waterproof. It seemed that not being able to wear the device around water, whilst restricting its utility for some participants, was not a high-priority concern.

In addressing concerns about size and appearance, future work should focus on further reducing the size of the device and providing users with an ability to customise the device's appearance. Customisation need not be unlimited, but rather a small range of different designs could be offered, with designs being selected by polling the user population for their preferences. The attachment to users' wrists should similarly be designed through greater testing with the user population, to determine what people feel is comfortable and to evaluate different designs with different wrist sizes. Overall size of the device would be addressed in the natural course of moving from prototypes to a more polished, finished product.

The Activthings device does not incorporate any algorithms to detect the location in which the device is being worn, so I had specifically instructed participants to wear the device on their wrist to maximise the effectiveness of both the ambient display and the accelerometer's activity-tracking capabilities. However, I asked them to report all the locations they had actually worn the device and where they wore it most of the time. All but one participant wore the device on their wrist or lower arm most of the time, giving confidence that the device was recording physical activity in a manner consistent with my pre-study preliminary evaluation. The remaining participant answered that they mostly carried the device in a bag. In terms of secondary wear locations, three users wore the device on their ankle or lower leg, two each carried the device in a waist pocket, in a leg pocket, and a bag, one user wore the device on their chest, and one wore it on their foot or shoe.

Pre-study testing of Activthings' accelerometer found that it was possible for the limits of the accelerometer to be exceeded during high-impact activities when worn on the ankle, resulting in clipping of the data. Further, use of the device on the ankle tended to bias a user's activity average such that less credit was awarded for the same activities when the device was later placed back on the wrist. Similarly, in testing it was found that the accelerations recorded when the device was placed in the user's pocket were higher than when the device was worn on the wrist, with the same effect of biasing the activity average. The degree of activity detected by having the device in a user's bag would depend on how and where (and if) the bag was carried during physical activity. The device would have tended to over-report activity when worn on the leg or shoe, as in this location it undergoes greater acceleration and deceleration as a result of physical activity, particularly those activities that involve high impact to the lower limbs such as brisk walking and running.

The decision to wear the device on the ankle or in a pocket may have been related to the device's bulk and appearance. Especially in situations where the participant did not feel it would be comfortable or appropriate to wear the device openly, they may have concealed it in a pocket or under clothing in the hope that it would nonetheless still record some physical activity. It could be expected that further work on the aesthetics of the device would obviate this need.

5.3.2 Ease-of-Use

In the Activmon study I identified battery life and charging as two key usability issues. Whilst it was impractical to give Activthings a greater battery life, I created a charging cradle with the intention of making charging simpler and less demanding. To evaluate the success of this measure I asked users to address statements about the convenience of charging, remembering to recharge the device and perceived battery life.

Of users responding to the post-study questionnaire ($N = 34$), 77% disagreed that "charging Activthings was inconvenient", 71% said they "remembered to charge Activthings most days", and only 31% responded that "the battery didn't last long enough".

> "The battery-life was abysmal. If I charged it overnight I would only get until about 2 or 3pm in the day and then it would shut off." *A738/A6*

> "[Naming a least-liked aspect] The requirement to recharge every night" *A993/A5*

Whereas in the Activmon study I had provided users with mobile phones, I asked users in this study to connect Activthings to their own phone. This provided increased convenience for users (in not having to carry two phones) and saved the expense and complexity of sourcing 40 phones for the study. It also reflected the way in which Activthings would be used in the real world—the device would have to work with a range of different models of phone, be able to be connected by the end-user and remain connected.

54% of users agreed that "It was easy to connect Activthings to my phone". Nonetheless, some experienced difficulty:

> "The need to constantly access the internet [*sic*]. Turning my mobile data on meant that my credit would disappear quickly, so I would not wear ActivThings [*sic*] as much to save money. Also having no internet [*sic*] connection means that I could use ActivThings [*sic*] when travelling, instead of having to leave it behind due to lack of internet [*sic*]." *A513/A1*

> "I was incredibly disappointed that activthings [*sic*] would not stay connected to my phone while at work. I should have asked if it connected to my laptop as that is always in close proximity." *A658/A7*

An anecdotal argument that I have heard advanced against wearable computing technologies is that it is inconvenient to have additional devices to carry around and charge. Although feedback from study participants certainly indicates that users would prefer to carry fewer devices if possible, the results of this study would suggest that this is a problem that can be overcome with the “right” device. The majority of users clearly felt that a one day battery life was adequate and that charging the device was not onerous.

The design of the charging cradle—one that was effective and simple to use—ultimately contributed to this sentiment. As I have proposed earlier, wearable devices might lend themselves to a certain type of “human battery interaction” (Rahmati et al., 2007), where users integrate charging into their daily routine. The provision of a charging cradle over a cable reduces the need for conscious thought around charging, reducing or eliminating a source of perceived annoyance or inconvenience.

A future design might consider better handling situations in which the user’s phone, or an Internet connection, is not available. The current behaviour is to deactivate the ambient display if the users’ phone is disconnected for longer than an hour, instead showing an error display. An alternative would be to have a flashing indication that would notify the user of a problem without removing the individual display. In the case of the group activity display there could be a way to indicate that the ranking shown is out of date, whilst not removing the ranking entirely.

5.3.3 Usage as an Indicator of Usability

In Section 3.3 I argued that the frequency with which devices are worn, and the average hours worn per day, may be indicative of user acceptance. Poor compliance with wearing a device during a study, or low wear time, in the presence of a poor response to questionnaire items, could indicate that the device is poorly designed or not functioning as intended. For this reason, I analysed the usage statistics for devices in the Activthings study and compared them to the earlier Activmon study, to gauge whether I had succeeded in increasing usability and utility over the previous

Did you stop wearing Activthings before the end of the study?	
Yes	21
No	14

Table 5.4: Participant retention

design.

Of a total of 42 participants, half were still using the device at the end of six weeks. Excluding three participants with unresolvable technical issues, the retention rate was 55%. Excluding six participants who either had unresolvable technical issues or never wore the device, the retention rate was 58%.

A third of participants used the device almost every day during the study. Just over a quarter of participants wore the device for most waking hours each day (where a day could be expected to have around 16 hours of waking time). Half the participants wore the device for the majority of their waking hours (8 hours or more). Excluding the six participants who had technical problems and/or didn't return any data, a third wore the device for ten or more hours on average each day. Excluding those participants who used the device on only a few days, the remainder used it for 10 hours per day on average. (Figure 5.11)

I asked participants whether they wore the device and if they stopped wearing it before the end of six weeks. The results aligned with the empirical data. Of the 36 participants who responded, 21 reported they stopped wearing the device before the end of the study, and 14 reported wearing it to the end. (Table 5.4)

I asked users why they did and didn't wear the device (Table 5.5). Forgetfulness was the most frequently mentioned reason for not wearing Activthings and/or stopping wearing it before the end of the study:

> "I forgot to put it on my wrist in the morning" *A513/A1*

Reasons Not Worn	Times Mentioned
Forget to wear/charge it	11
Incompatible activity (camping, swimming, job requirements, rain, washing up)	11
Unattractive or didn't want to wear certain places	10
Device malfunctioned/turned off/ran out of power/charging was a hassle	8
Problems connecting with phone/reception/Internet	6
Involuntary—was ill/travelling	6
Too many people asking questions/didn't want to explain it	5
Uncomfortable/bulky	4
Didn't believe it was working properly/inaccurate	3
Couldn't get it to go green	1
Didn't feel I needed it anymore	1

Table 5.5: Reasons participants didn't wear Activthings

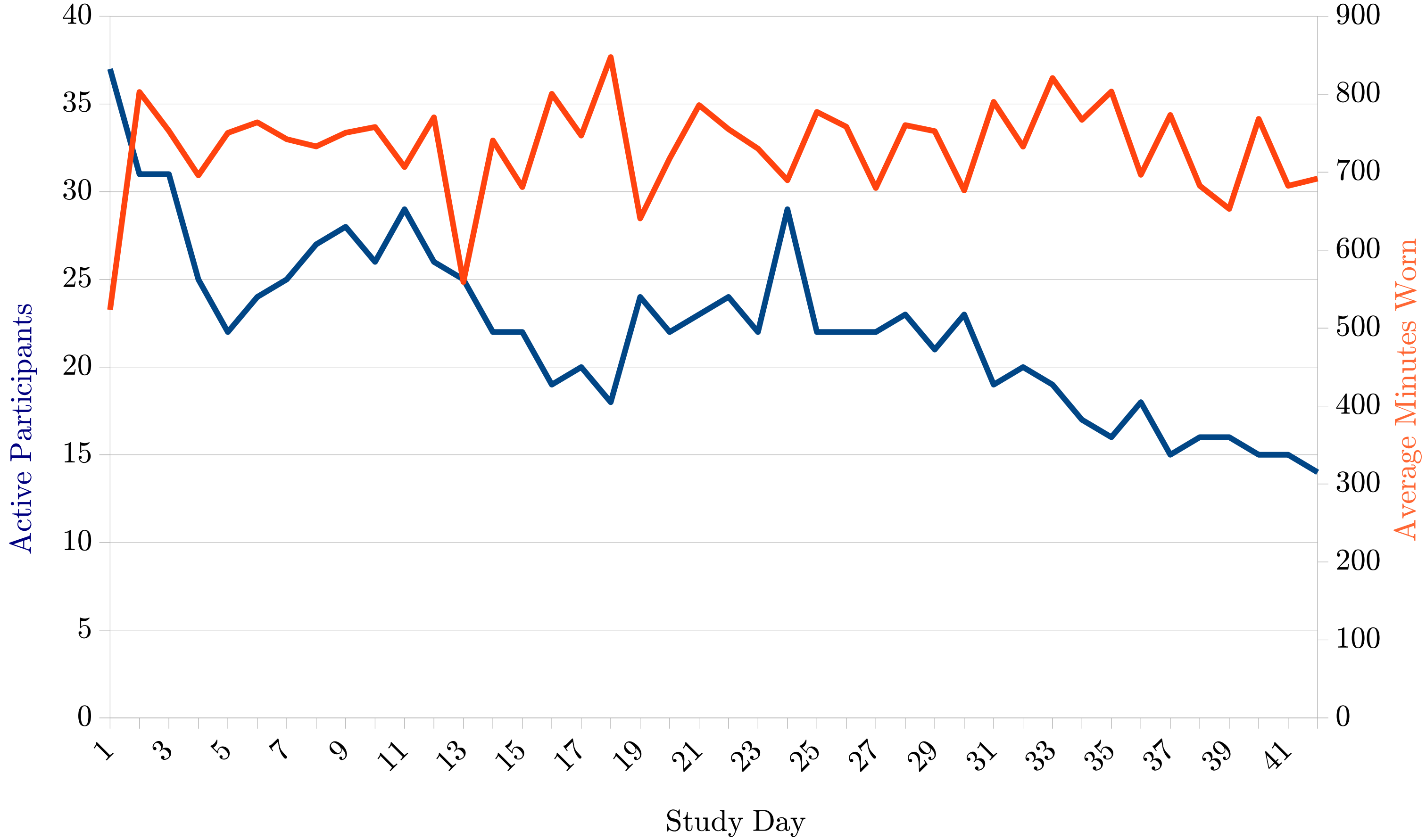


Figure 5.11: Participation over the study period

> "When I was particularly busy/running late I forgot to put it on" *A835/A4*

The other equally common reason was incompatibility with participants' lifestyles, professions, or exercise regimes. Some participants reported going camping or hiking during the study and being unable to charge the device due to lack of access to electricity. Others had to remove the device, or didn't wear it, due to concerns about water entering it during swimming, washing up or during wet weather.

> "[I] went camping and had no way of recharging the device" *A119/A1*

> "It . . . got in the way with some manual tasks and had to be careful with/near water" *A247/A2*

> "Last weekend I went for a run in the pouring rain and I believe the device isn't waterproof, so didn't want to damage it" *A61/A2*

The second most commonly mentioned reason was that the device was unattractive or that participants didn't want to wear it in particular situations. For example, on some formal, business, or social occasions Activthings was seen as unattractive, socially inappropriate, or not in keeping with the participants' clothing or desired appearance.

> "[It] did look a bit like a house arrest band" *A247/A2*

> "I didn't wear it to some client meetings because people thought I was on home detention" *A769/A7*

> "It is a bit large so sometimes I was going to a function where it was not really smart enough to wear" *A425/A4*

> "I didn't wear it in the cinema because I didn't want the light to distract other viewers. I figured I would be sitting anyway" *A909/A4*

Several participants reported having difficulty connecting the device to their phone or the Internet, or the device malfunctioning or running out of battery prematurely:

> "Some days the battery wore out half way through the day and I'd put it on the charger and forget to put it on again" *A769/A7*

> "I had connectivity issues on some days and took it off" *A311/A5*

Others said, at least some of the time, they wanted to avoid questions from onlookers about the device:

> "Sometimes I didn't wear it if I didn't want to be questioned about it" *A738/A6*

> "[I didn't wear it] if I was going out and didn't want to have to explain what it was" *A194/A8*

A common response to the question of why users wore the device was that the device was comfortable or became a natural part of the participants' wardrobe, suggesting that efforts to make the device integrate into a user's everyday life were moderately successful. This also highlights the importance of designing to facilitate such integration.

> "It was just part of my daily wardrobe" *A152/A3*

The number of participants who reported leaving the study before the end was slightly higher than the raw usage data would suggest. A possible explanation is that I was sometimes slow in letting a participant know that their six weeks was over. They may have actually lasted the whole six weeks before deciding to discontinue use of the band but counted themselves as having left the study early because they hadn't been told their time was already over. It does show however, as could be expected, that the drop-out rate would have been higher the longer the study had continued to run. In the group conditions the withdrawal of one or more users of a group may have hastened the withdrawal of the remaining members, especially in the group display only conditions.

5.3.4 Summary

Overall, the design of the Activthings device was effective in increasing user satisfaction and wear time, compared to the previous Activmon device. The use of a 3D-printed housing yielded a device that was more attractive and comfortable than the Activmon device, resulting in average daily wear time increasing from eight to ten hours per day. Most users wore the device on their wrist. Users were still concerned about the size and appearance of the device, however the device was nonetheless able to gain user acceptance over six weeks. These results give confidence for the use of rapid prototyping technology, such as 3D printers, where it is necessary to produce novel wearable interfaces for a user study in a short period of time with limited resources.

Battery life and charging did not appear to be significant concerns to users, in contrast to the Activmon device where they were. The use of a 3D-printed charging cradle may have helped to improve perceptions of battery life and ease of charging, by making the charging process simpler and less burdensome to the user. Rapid prototyping technologies enable this sort of "troubleshooting", where a new design element can be quickly introduced to address user concerns from previous design iterations.

The majority of users were able to successfully connect their own phones to the device, although there were some specific models that were incompatible. Activthings connected to the Internet less frequently than the Activmon device, meaning dropped connections were better tolerated and mostly invisible to the user. The inability of the device to "degrade gracefully"—to retain some functionality while disconnected for an extended period—did, however, frustrate some users.

User retention, consistency of wearing the device and number of hours worn per day were good, with the equal most common reason users didn't wear the device being that they simply forgot. This implies usability was adequate and there were no serious barriers to user engagement. Remaining concerns were that the device was incompatible with certain lifestyle activities, either due to it not being waterproof or discreet enough in sensitive situations.

5.4 Motivation

In Section 3.2 I proposed three evaluation criteria relating to motivation: monitoring, which refers to whether users notice the information presented, reflection, which is whether users reflect on the information they have seen and discuss it with others, and engagement, which refers to whether users engage in continuing monitoring that could eventually lead to behaviour change.

5.4.1 Monitoring and Reflection

In the post-study questionnaire, of users who received the individual activity display ($N = 27$), 67% said that they looked at the individual light often. 59% said they noticed the light turn yellow or red when they hadn't exercised and 52% said they saw the light turn yellow or green when they had. 78% of participants disagreed with the statement “I didn’t care what colour the light was”, with 41% saying they felt upset when the light turned red and 78% saying they felt happy when the light turned green. 63% said they felt they had control over the colour of the light. (Figure 5.3)

Of users who received the group display ($N = 14$), 71% said they noticed the ranking lights change position and 57% said they looked at the ranking lights often. Only 36% of users, however, said they were happy when they moved to the top of the rankings and 86% disagreed that they were upset when they moved to the bottom of the rankings, revealing a weaker response to this display than for the individual display.

The problem of lack of concurrency within some groups, and anonymity of group members, was obvious in users’ responses. 79% of users disagreed with the statement “I felt I had control over my position in the rankings”, 78% said they didn’t notice themselves moving up in the rankings, and 79% said they didn’t notice themselves moving down in the rankings. Only 36% felt the ranking system was “fun”. (Figure 5.5)

I asked users why they wore Activthings and what they liked most about it. The equal most common response users gave for wearing the device was that they felt the device reminded, encouraged, or motivated them to be active, increased their awareness of their activity levels, or gave them a target to work toward. (Table 5.6) This was also mentioned frequently as a most-liked feature of the device. (Table 5.7)

Users commented:

> “It encouraged me to be active” *A299/A3*

Reasons Worn	Times Mentioned
Commitment to the study/interest in results	7
Encouraged/reminded/motivated me to be active/increased awareness/gave me a target	7
It was comfortable/became part of my wardrobe	3
Enjoyed the competitiveness, liked comparing to others	2
Wanted to receive credit for being active	2

Table 5.6: Reasons participants wore Activthings

What did you like most about the Activthings device, wearing the device and the study?	Times Mentioned
Motivation/inspiration/challenge/encouragement	10
Visibility/acted as a reminder to do more/made me think	8
Attention from others/conversation starter/it was cool	7
Seeing how much I was doing/information	4
Simplicity/easy to wear	4
The ranking/competition	3

Table 5.7: Aspects participants liked

> "It made me more aware of the exercise I was or was not doing" *A385/A7*

> "The realisation that change was easier to make than expected/dreaded" *A624/A3*

The second most commonly liked aspect of Activthings was its visibility and the way in which it acted as an explicit or implicit reminder to be more active:

> "The visibility of the device, not to mention that I kept looking at it to check the time, meant that I was always reminded of my activity level. I found this to be helpful, and I think that if it was not worn on the wrist or somewhere of equivalent visibility then the effect would be lost." *A31/A5*

> "I found it interesting to compare how I was achieving my goal against other people, and because of its visible position on my wrist it served as a reminder that I should be doing more" *A311/A5*

> "It kept my activity (or lack of it) front of mind. I liked the challenge of making it go grean [*sic*]." *A61/A2*

Some users described becoming invested in getting credit for their activity:

> "For the short time I used it, I felt that I had to do something to get that green light. Inspiration!" *A299/A3*

In questionnaire responses, participants also talked about how the device encouraged them to get into conversations with other people about health, indicating they were motivated to think about their physical activity as a result of wearing Activthings and that it caused them to engage socially with their physical activity. Some participants indicated a positive impact from experiencing the reactions of others to their display:

> "The satisfaction of seeing other people see my green light and be impressed! Lol! As a morbidly obese individual, it is nice to have something to show people that I am not a lazy 'never do exercise' person (which is such a stereotype!), and that I can sustain a green light! Terrible, isn't it?!" *A909/A4*

A few participants who received the group display commented on the value of competing against others:

> "I liked the competitiveness of the Activthings system" *A119/A1*

> "Activthings encouraged me to exercise, and I hated other people in the study being more active than me! Activthings appealed to my competitive streak!" *A658/A7*

The simplicity of the display and ease of use and wearing was also mentioned as a most liked feature.

These results demonstrate that the majority of users engaged in at least basic monitoring of the individual ambient display. Further, even users who looked at the light infrequently, or didn't notice it changing colour, still reacted to the colour and what it represented when they did look at it.

The strong response that users liked the light turning green is encouraging—it demonstrates a personal response to the information presented that goes beyond mere comprehension. It was positive to see that more users felt happy having the light turn green than those who reported feeling upset when the light turned red. This shows that even if the display is providing negative feedback users are not likely to feel demotivated.

5.4.2 Engagement

The monitoring, comprehension and discussion behaviour shown above, if continued over time, should result in actual behaviour change that would be measurable in participants' actual physical activity levels, self-reported physical activity or psychological measures of behaviour change. Although Klasnja et al. (2011) warn against using these measures to determine "efficacy" in a short-term study, I nonetheless felt they could assist in the interpretation of the abovementioned qualitative results, and provide some direction as to the evaluation of Activthings in a future long-term study.

Over the course of the study, participants' devices created 151,629 five-minute activity reports, representing a combined 12,636 hours of physical activity data.

Prior to analysing these data I excluded the five participants who returned no data[1], five participants who returned data but withdrew before the end of the study and two who returned less than seven days of data. In the case of participants who returned no data, their reasons for not engaging with the device have been discussed previously (Section 5.3.3). For the participants who withdrew or returned little data, I was concerned that including them in the analysis would produce unreliable results, as they had not worn the device for sufficient time to allow me to determine if it had any effect.

For the remaining 30 participants I calculated a median-filled seven day sliding window average of their reports for each day of the study period, up to 42 days for each user from the date they first started using their device. In this process I further excluded all zero reports, as these most likely represented periods of time the user left the device turned on while not wearing it, generating false data.

For those who received the individual display ($N = 24$), I graphed their daily sliding window activity averages alongside their goal and red line values for the corresponding days. These graphs show how users' activity influenced their weekly goals and/or how the goals provided affected users' activity levels. Some users, such as A600 (Figure A.1), maintained a very consistent level of activity over six weeks, staying mainly within the yellow zone but occasionally increasing activity when approaching or falling below the red line. Others, such as A909 (Figure A.2), were able to increase their activity levels but appeared to only maintain this increase in the short term. Some users, such as A152 (Figure A.3), had very volatile levels of activity which had a poor fit with the display's red-to-green range.

To determine whether there was a general trend toward either increasing or decreas-

[1] This included the the two participants who withdrew and were replaced

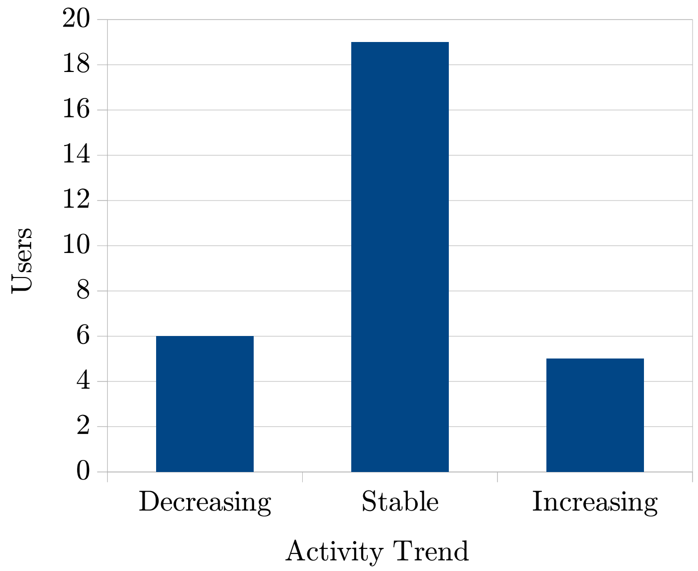


Figure 5.12: Linear Regression Coefficient Trends

ing activity over the period of the study, I performed a linear regression of users' daily sliding window activity averages using the simple model:

$$y_i = \alpha + \beta x_i + \epsilon_i \tag{5.1}$$

Overall, more participants increased in activity than decreased. Considering slopes of between -5000 and 5000 counts per hour per day to be not significant, however, most users' activity remained stable. (Figure 5.12)

I then graphed the slopes of the linear regressions for each user, in decreasing order of slope (Figure 5.13). The magnitude of negative slopes was higher than for positive slopes. For this reason the average slope ($M = -774.6, SD = 8933.63$) was in fact negative, although this was not statistically significant ($t(29) = -0.47, p = .64$ two-tailed). The average slope for individual display only conditions was marginally positive ($M = 1884.59, SD = 4852.95$), whilst for group conditions it was negative ($M = -4252, SD = 11762.41$), however neither was statistically significant ($t(16) = 1.60, p = .13$ two-tailed, and $t(12) = -1.30, p = .22$ two-tailed, respectively).

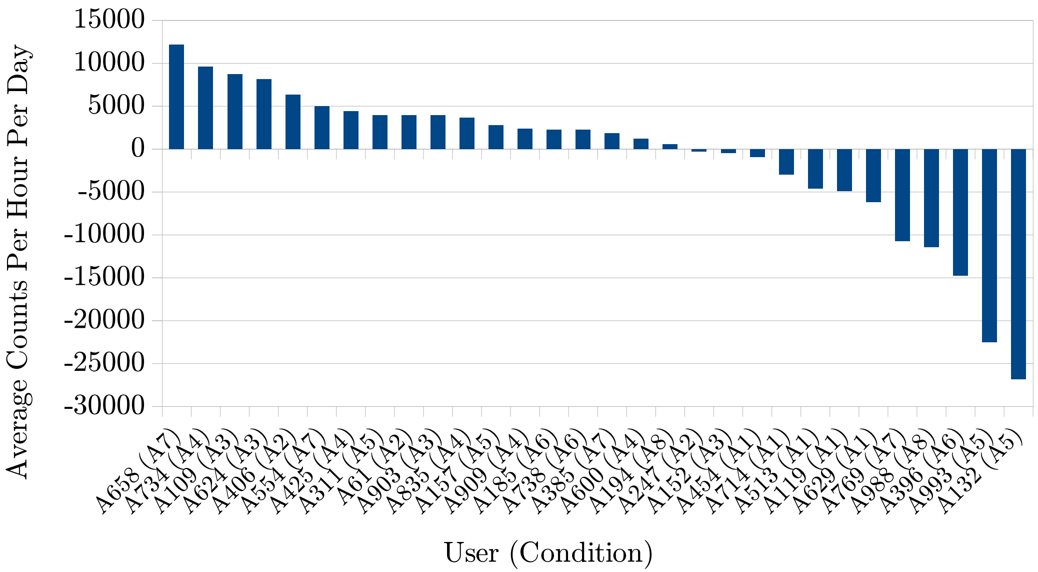


Figure 5.13: Average Activity Linear Regression Coefficients

The overall fit for these regressions was poor ($\mu_{R^2} = .24$), due to the non-homogeneity of users and conditions. In order to better understand the effects of individual user variability and choice of condition on physical activity, I employed a mixed-effects linear model approach (Bates, Mächler, Bolker, & Walker, 2015), using the R statistics package (R Core Team, 2016), to construct different models including these effects.

I modelled the effect of condition on activity as follows.

$$Activity \sim Day * Condition + (Day|User) \tag{5.2}$$

Where *Activity* is the dependent variable, *Day* (time) and *Condition* are fixed effects, and $User$ is a random effect. The fixed effects of *Day* and *Condition* are crossed, in that I expected that each condition would affect the activity of users in that condition differently over time. The random effect of $User$ has both a random intercept and slope, with the slope varying with time, in that users may have different starting points and rates of activity, regardless of condition. The slope and intercept for each user are assumed to be interrelated, in that the rate of activity may depend on the starting point (as more active users may increase activity at a slower rate or vice-versa).

All four group display conditions (A5–A8) had negative slopes, indicating a decrease in activity for participants in those conditions over the course of the study. In contrast, individual display conditions A2–A4 had positive slopes, indicating increases in activity, with A1 being the only individual display condition with a negative slope. Intercepts for each condition showed significant variability, with the intercept for condition A5 being almost twice that of A3 and A8. This indicates a difference in initial activity levels between users in each condition, with some users being much more active than others when starting to wear the device.

I performed likelihood ratio tests to compare models with fixed effects for *Condition*, crossed with *Day*, with a base model, with only *Day* as a fixed effect.

$$Activity \sim Day + (Day|User) \tag{5.3}$$

For users in individual conditions, the selection of *Condition* affected the amount of physical activity performed ($\chi^2(14) = 18.342, p < .01$). Modelling all users in all conditions, however, the choice of condition was not significantly associated with physical activity ($\chi^2(14) = 17.51, p = .23$).

The per-user slopes in the base model roughly aligned with those of the individual linear regressions, shown previously. Again, neither the average slope overall ($M = -799.23, SD = 7414.76$), the slope for individual only conditions ($M = 1861.45, SD = 3812.53$), or the slope for group conditions ($M = -4737.56, SD = 9671.91$), were statistically significant ($t(29) = -0.59, p = .56$ two-tailed, $t(16) = 2.01, p = .06$ two-tailed and $t(12) = -1.77, p = .10$ two-tailed, respectively).

Considering the selection of red and goal thresholds for users in individual conditions, I constructed the following models.

$$Activity \sim Day * RedThreshold + (Day|User) \tag{5.4}$$

$$Activity \sim Day * GoalThreshold + (Day|User) \tag{5.5}$$

The first model considers the red threshold to be a fixed effect, whereas the second considers the goal threshold to be a fixed effect. These correspond to the collapsed conditions discussed in Section 5.1. Both include a random effect for variability due to individual users.

The low red threshold and low goal threshold groupings both had positive slopes, indicating an increase in activity. The high red threshold and high goal threshold groupings had negative slopes, indicating a decrease, although not to the same magnitude as the increasing slopes. Performing likelihood ratio tests to compare both models with the base model, I found that the selection of a red threshold was significant ($\chi^2(2) = 8.0492, p = .02$), however the selection of a goal threshold was not significant ($\chi^2(2) = 3.9231, p = .14$).

Other fixed effects that were not significant were the type of display presented to the user (individual only, group only, or a combination) ($\chi^2(4) = 8.2121, p = .08$), the type of group display (group only or a combination) ($\chi^2(2) = 3.1705, p = .20$), and the choice of a long or short ranking time, for group display users ($\chi^2(2) = 0.397, p = .82$).

For each of the collapsed individual and group categories (as per Figures 5.1 and 5.2), I averaged users' seven day sliding window activity averages for each day as well as users' goals for each day. Average activity and goals in the "high goal" and "high red threshold" groupings were flat over six weeks (Figures A.4 and A.6). Average activity and goals in the "low goal" and "low red threshold" groupings appeared to increase (Figures A.5 and A.7). The "combined" and "group only" groupings showed a slight decline in average activity and goals (Figures A.8 and A.9).

For each user I calculated the correlation between sliding window average activity values at the end of each day, and their goals for those days (Figure 5.15). For most users there was a modest positive correlation, indicating adherence to goals. I expected that most correlations would not approach 1, however, as the action of setting weekly goals to be above users' average activity would mean that, at least some of the time, users would be below their goal and working up toward it.

I averaged the correlations for the high goal, low goal, high red threshold, low red threshold, combined and group only collapsed conditions (Figure 5.14). Users in the high red threshold and high goal groupings had the lowest correlations, whilst users in the low red threshold and low goal groupings had the highest correlations. Users in the combined and group only groupings, whose goals were calculated using a high goal and low red threshold, had the highest correlations.

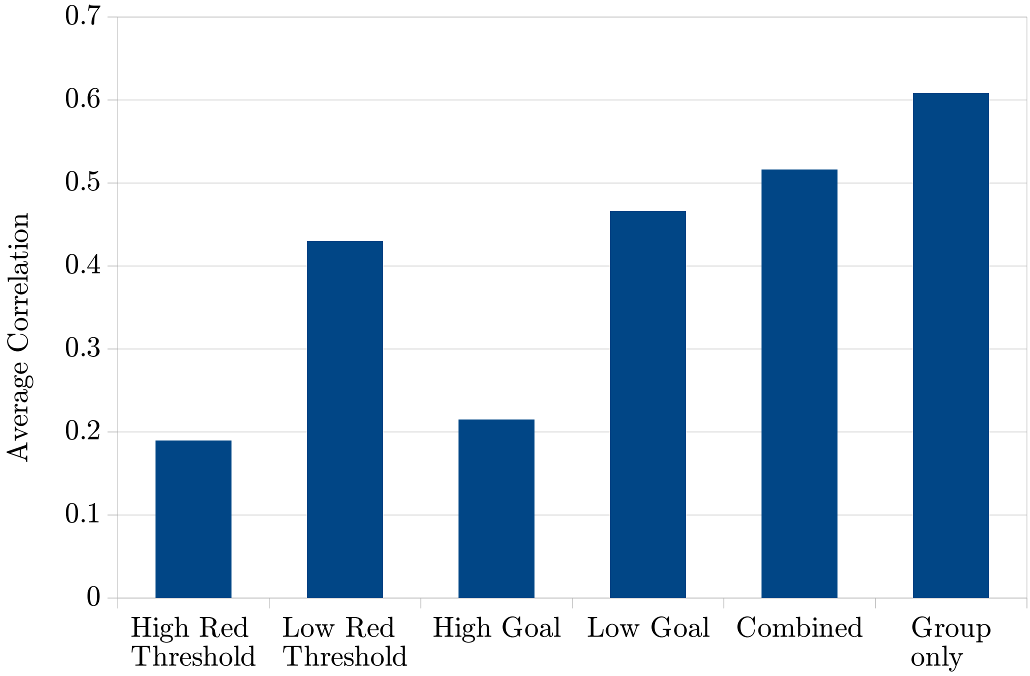


Figure 5.14: Average correlations for collapsed conditions

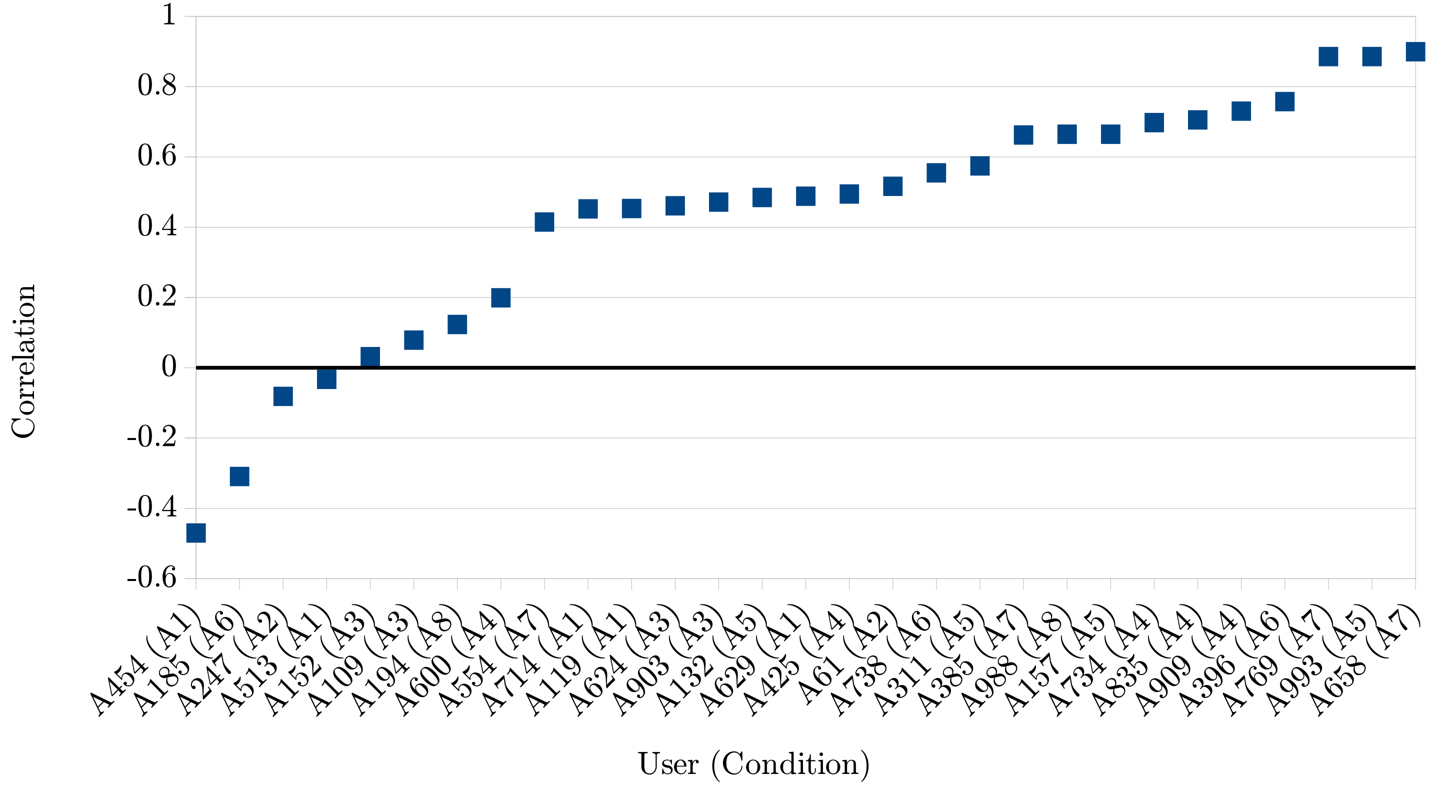


Figure 5.15: Correlation between activity and goals for each user

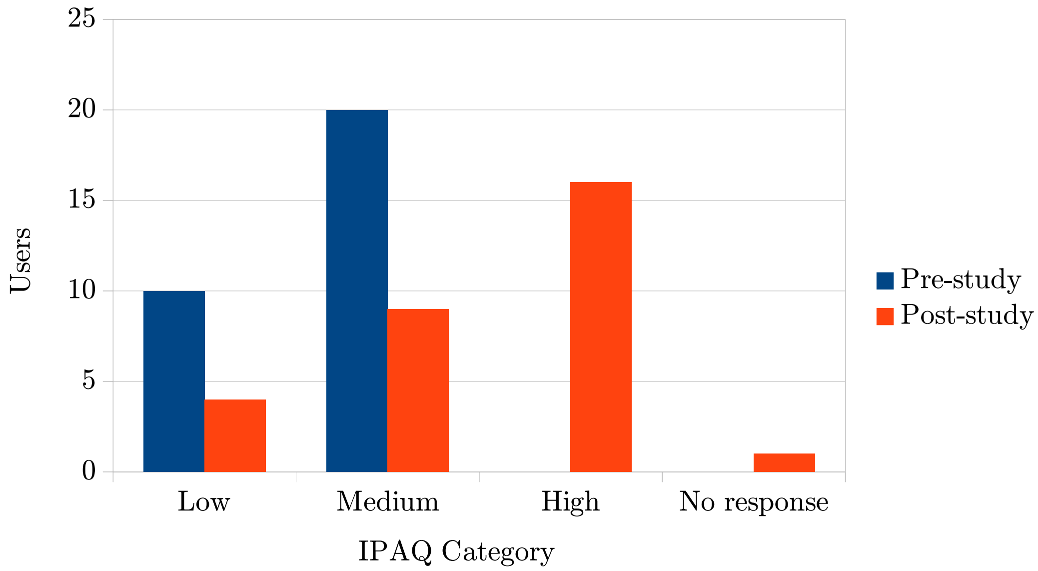


Figure 5.16: Participant IPAQ categories pre- and post-study

The positive slopes for the low goal and low red threshold groupings were statistically significant ($H_1 : \mu > 0$ $t(7) = 3.61, p < .01$ and $t(7) = 3.46, p < .01$, respectively), however the fit of the regression was poor. The average daily activity-to-goal correlations for these conditions, however, were higher than for the high goal and high red threshold groupings.

I asked participants to complete a short-form International Physical Activity Questionnaire (IPAQ) post-study, in order to determine whether there was any increase in self-reported physical activity over the study period. Compared to participants' sign-up baselines ($M = 1153.14, SD = 705.08$), post-study MET minutes/week ($M = 3217.41, SD = 3207.92$) were significantly higher ($t(28) = -3.739, p < .01$). The majority of participants were rated in the "high" category post-study (Figure 5.16).

A pre-study histogram of MET minutes/week shows a clear mode of 1000–1500. Post-study the distribution is bi-modal at 1500–2000 and 3000–3500 MET minutes/week, showing at least part of the study cohort are reporting higher levels of physical activity. Most participants responded one to two weeks after finishing the

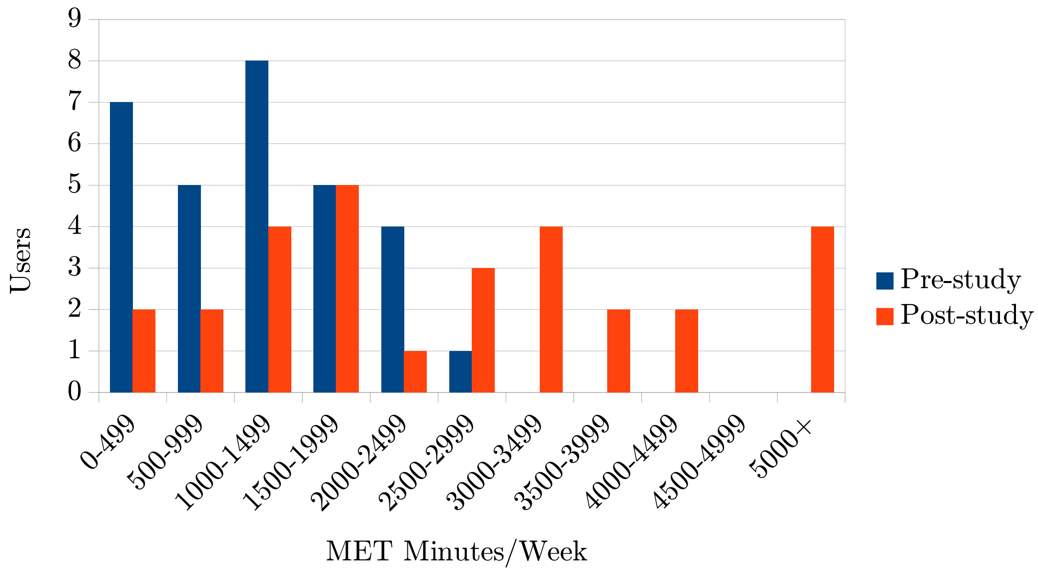


Figure 5.17: Pre- and post-study IPAQ MET minutes/day

study, yet they still reported higher levels of activity. (Figure 5.17)

I asked participants a series of 18 questions pre- and post-study designed to measure their self-efficacy for exercise regulation, such as, "rate how confident you are that you can stick to doing regular physical activity... when I am feeling under pressure from work". Participants rated each statement on a scale from 0–100 (in ten unit increments), where zero represented "Cannot do at all", and 100 represented "Highly certain can do", with the middle (50) representing "Moderately can do". In scoring responses, I summed the values and divided by ten (reflecting the fact that each response actually had ten possible non-zero answers).

Comparing participants' responses pre- and post-study ($M = 96.55, SD = 33.06$ and $M = 97.17, SD = 32.48$, respectively), there was no statistically significant change ($t(28) = -0.14, p = .89$) (Figure 5.18). Self efficacy did not appear to have been affected by participation in the study or use of the Activthings device.

I asked participants whether, overall, they got what they were looking for from their participation in the study. The majority of respondents felt they had benefited from their involvement in the study, although responses ranged between those that felt

Figure 5.18: Pre- and post-study self-efficacy

Did you get what you were looking for?	
Yes	16
Somewhat/unsure	4
No	11

Table 5.8: Participant satisfaction

the intervention had been a failure and those that claimed their participation meant they were now more active, healthier and eating better. (Table 5.8)

The analysis of correlation between goals and activity provided a further indication that users respond best to a low goal, low red threshold individual display. The higher correlation for the low goal grouping, however, might simply have been a reflection of the fact that users' goals will be closer to their activity average at the beginning of each week than for high goal conditions.

Participants' perceptions, in IPAQ responses, of being more active post-study are not supported by the actual physical activity data. It is possible that participants began engaging in more physical activity from the start of the study, as a result of receiving the Activthings device, and are therefore correctly reporting an increased level of activity above a historical baseline that was not captured by the devices.

The data give some weight to this theory—over half the users had increased, flat, or marginally negative activity trends, and retention and use of Activthings, at least for the first month, was very good. This might mean that Activthings was successful in helping users sustain regular activity over the study period, at a level higher than that of the pre-study period.

Another possibility is that participants are reporting more physical activity due to higher consciousness of physical activity behaviour, as a result of participating in the study. As Activthings credits wearers for physical activity above the wearer's usual baseline that may not necessarily fall under the umbrella of traditional exercise, over the course of the study Activthings would naturally make wearers more conscious of behaviour they might not previously have classified as physical activity.

The possibility that self-efficacy was not affected is an interesting result, especially when contrasted against the finding of higher self-reported physical activity, and evidence that users were engaged to think about and discuss physical activity. I have previously raised the argument of Klasnja et al. (2011), that day-to-day activity levels are far too volatile a measure with which to evaluate the efficacy of an intervention in a short-term study. Any apparent increase provides no indication of the potential of an intervention to effect real psychological change, that could lead to sustainable long-term outcomes. An increase in self-efficacy over such a short single-factor intervention study would actually have indicated that self-efficacy was vulnerable to such short-term fluctuations, and therefore not a reliable, stable measure of change. That self-efficacy did not appear to be affected in this case could indicate that it is a reliable indicator of long-term behaviour change. This would need to be verified in a longer duration study, where self-efficacy would be measured at several points through the study to measure any change with greater granularity.

5.4.3 Summary

Users who received the individual display reported monitoring it, being concerned when it was red and happy when it was green. This indicates a personal response to the display, where users have internalised the information presented and reacted to it.

User anonymity, users dropping out and a lack of concurrency in some conditions, meant the group display was not as effective as it could have been. Users did not report monitoring or reacting to the group display in the same way as they did with the individual display. At least some users, however, reported being motivated by the group display, suggesting a different evaluation methodology could yield better results.

I was able to provide evidence in support of the theory of Lim et al. (2011), that a highly visible wearable ambient display could motivate users by engaging them in discussions with others about the information presented. Almost all users reported being asked by others about the display device and some said they felt this interaction was helpful.

I did not expect to demonstrate actual behaviour change in this study, and the activity data collected by the devices did not show any significant increase. Users' self-efficacy for exercise regulation did not increase. Self-report physical activity did increase, suggesting increased awareness of physical activity or a "plateauing" effect that was not properly measured by the evaluation methodology used.

I was able to draw some conclusions about elements of the displays affected users' physical activity. It was surprising that, for the individual activity display, the choice of red threshold had a statistically significant effect on users' activity, whereas the choice of goal threshold (either five or ten percent above average activity) did not. This indicated that the treatment of recidivism by the display was more important than the difficulty of achieving a reward (the goal). Perhaps users who received a high red threshold, which provided greater disincentive to engage in sedentary behaviour, were demotivated, and this was reflected in their activity levels over the course of the study. This suggests a strong focus on this aspect of activity displays is warranted, in addition to focussing on goals.

Of the individual conditions, the high-red threshold, high-goal condition appeared to be poorly received. It provided little scope for recidivism, while having challenging goals. Additionally, the condition was unbalanced, in that it would have taken comparatively more activity to reach a green colour (the goal) than it would to reach a red colour (the most sedentary state that could be shown). Given the alignment of the thresholds, a sustained level of activity consistent with the user's long-term average would have produced an indication tending toward the red end of the colour spectrum, providing negative feedback even in the absence of sedentary behaviour.

Whilst, at an aggregate level, the choice of individual condition and selection of a red threshold were significant, it was not possible to conclude that any particular condition was better or worse than another. There were too few users in each condition. These findings do, however, provide a direction for future research—another study with the same number of users, but fewer conditions, could concentrate specifically on the effect of red threshold selection.

Similarly, it was not possible to say from the activity data that the addition of a group display was significant, nor which ranking method was best. The poor results from users in group conditions were likely due to problems with the study design—users didn't know each other and some users dropped out prematurely, leaving too few users in some conditions.

Overall, I showed that the putative active elements of Activthings—the display of activity information, and the engagement of users with that information—were functioning correctly (Klasnja et al., 2011). I was able to gain insight into aspects of the design of the wearable device and displays that were effective at supporting these elements. A future study would attempt to measure actual behaviour change over a longer period of time.

Chapter 6

Conclusions

6.1 Overview

In the present age of ubiquitous computing, computers are playing a more intimate role in people's lives, particularly in health monitoring. The effectiveness of an intervention in prompting behaviour change is predicated on first establishing the behaviour of regular engagement with the intervention. The majority of computer-based interventions intended to promote increased physical activity employ high-complexity, high-engagement displays, relying heavily on text, numbers and graphs. Less attention has been given to the possible use of low-complexity, low-engagement displays using simple metaphors to convey information, such as ambient displays, even though these interfaces could have the benefit of appealing to users who are less engaged with their health.

Examples of ambient displays used to present physical activity information are the UbiFit Garden interface of Consolvo et al. (2008) and the Fish'n'Steps interface of Lin et al. (2006). However, these displays presuppose the user is engaged in some unrelated behaviour in order to see the ambient display—using a mobile phone, in the case of UbiFit Garden, or walking past a fixed screen or looking at a web page, in the case of Fish'n'Steps. This requirement for "pre-requisite" behaviour may limit monitoring of the ambient display, or result in monitoring occurring at times the user is not primed to take action as a result of viewing the display.

There is the opportunity, therefore, to explore potential ambient display designs that minimise these engagement pre-requisites. One little-explored possibility is that of integrating an ambient display into a dedicated wearable computer. Of the possible ambient information delivery mechanisms, light is the most practical and useful in this context. A wearable ambient display could create a persistently visible display, using variations of brightness and colour, to represent the user's level of physical activity and that of others. In attracting attention to the wearer, it could help to engage them in thought and discussion around physical activity (Lim et al., 2011).

In Section 1.4, I presented a number of unanswered questions around wearable ambient displays, and displays that convey physical activity information in particular. These questions related to the way in which information is presented, the design of display devices and their potential to motivate users to change their behaviour. It is these questions which I have attempted to address in this research.

6.2 Methodology

Similar to other work in the field, I decided to employ an experimental approach to answer these questions. I would provide various ambient displays to a group of users and measure, using both qualitative (interviews) and quantitative (questionnaires) instruments, their experiences with and response to those displays.

In selecting a specific methodology I had regard for the availability of suitable hardware with which to implement and evaluate a wearable ambient display. Commercially available wearable devices were unsuitable as none could create a persistently visible colour display. I therefore chose a design-based research methodology (Obrenović, 2011) in which I would design, construct and evaluate my own wearable ambient display devices.

I designed both an individual and group ambient display, as well as a prototype wearable display device—Activmon. To evaluate the displays and wearable device, I proposed a series of evaluation criteria, aligned with the research questions above (Section 3.2). I undertook a small scoping study, with five users over a two week period.

Based on the results of this scoping study I designed new individual and group displays, and a new wearable display device—Activthings. I employed rapid prototyping methods, such as 3D printing, to produce a significantly higher-fidelity prototype. I evaluated Activthings with a more substantial study of 40 users over six weeks.

I used mainly qualitative evaluation methods, including questionnaires with both Likert and free-form response items, and semi-structured interviews. Using these methods I sought to understand users' subjective experiences in the context of the evaluation criteria categories above. Responses regarding users' understanding of the information presented, perceptions of accuracy and the perceptions of others addressed information presentation criteria. Users' views on the appearance, comfort and practicality of each of the devices addressed design criteria. Reflection and engagement addressed motivation criteria.

The aim of this research was not to demonstrate behaviour change directly (which would require a longer-term study) but rather, as argued by Klasnja et al. (2011), to show that the putative active elements of the device were operating effectively. I therefore did not attempt to directly address the question of whether ambient displays could create long-term behaviour change. Nonetheless I did employ a number of behaviour change measures, in order to enhance the analysis and interpretation of the other mainly qualitative data. These methods included the International Physical Activity Questionnaire (IPAQ), a questionnaire to measure self efficacy for exercise regulation, and the recorded activity data from the wearable devices themselves.

6.3 Results and Conclusions

6.3.1 Information Presentation

Comprehension and Accuracy

My first individual activity display used a traffic light metaphor, where an RGB LED changed on a spectrum from red to green across the course of each day as the user undertook physical activity toward a daily goal. There were significant problems with this display. Users had the same goal each day for a week, even though it was difficult to reach on some days (weekdays) and too easy to reach on others (weekends). The colour resetting each day created a sense of endless "hill climbing". The inclusion of non-exercise (NEAT) activity added to the perception of inaccuracy.

For the Activthings device I attempted to address these issues by using a "continuum" approach, where the individual activity light would change colour toward red or green depending on the users' weekly activity compared to their long-term average. This had the effect of eliminating the "hill climbing" effect, of smoothing out daily variability and of better integrating NEAT activity in a way that was more seamless to the user.

Users of Activthings were split on the question of whether the resulting individual display was accurate and whether they could derive meaning from it. It appeared that some users, while not perceiving the display as inaccurate, still struggled to translate the information presented into a sense of meaning for them.

One explanation could be weaknesses in the goal setting system. Whilst, overall, users were satisfied with the goals they received there were problems with initial goal setting and downward adjustment. Initial goals calculated on the basis of three days' activity were inaccurate and may have harmed users' first impressions of the display—a longer period is indicated. Whilst downward adjustment of goals was supposed to prevent demotivation it appeared to have the effect of providing insufficient motivation and encouraging "yo-yo" behaviour—in future downward adjustment could be prevented or limited.

There was an association between the goal threshold (where the display would turn entirely green) and the red threshold (where the display would turn red), and perceived comprehension and accuracy. Users seemed to prefer a lower goal threshold and a lower red threshold. This is an intuitive result, as these settings provide easily achievable goals and a wide margin for recidivism. The small number of users in each condition, however, meant that it was not possible to draw any conclusions at this stage.

Overall, Activthings' individual display performed acceptably. Further work will be required to fine-tune the behaviour of the goal setting system and display parameters (red and green lines) to enhance comprehension and perceived accuracy.

The Activmon group activity display used flashing to represent the combined activity of users in the study group. The device's RGB LED would pulse when other users were active. Users understood that other people were being active when the light flashed, however their ability to derive meaning from the display was limited due to the simple nature of the notification. Users knew that someone else was being active but not who it was.

I implemented a more complex group activity display in the Activthings device. This display used a row of RGB LEDs to show each user a ranking of themselves against other group members. This allowed users to discriminate between different members in the group but the anonymity of participants limited its meaningfulness. Concurrent use was acceptable but could have been better, and users leaving the study decreased the quality of feedback for remaining users who were receiving the group display only.

It was clear that at least some users enjoyed the group display and felt that it motivated them. In future work I would recruit users who already know one another.

Whilst introducing a possible source of bias (participants could motivate one another directly) I would expect users' existing social structures would mean they would be more engaged with the information presented and more likely to wear the device.

Explicit Social Persuasion

Originally proposed by Lim et al. (2011), explicit social persuasion is where highly visible wearable displays engage the user in discussions with others about the information presented. These discussions prompt the user to reflect on the information presented and, if the discussions involve friends and family, they may feel social pressure to act on that information (for example, by being more active to ensure their friends always see them with a green light).

Weighed against this positive effect is the possible negative effect of failing to respect users' privacy and social context. Users may not feel comfortable having their physical activity information displayed at all times, or there may be situations in which this display is not appropriate.

Users who wore Activthings reported experiencing this explicit social persuasion effect—others noticed the device and asked them about the information presented, and this prompted them to think about own their level of physical activity. Users did, however, have concerns about the appropriateness of wearing such an overt display in certain business and social circumstances. For example, users felt that attending a friend's wedding or an important business meeting were situations in which it would be inappropriate to draw the attention of others by wearing something unusual or intrusive.

A common theme from both user studies was that people felt the devices looked like "tracking bracelets" that would be applied to criminals being monitored by the authorities. Despite the negative connotations, wearers said they enjoyed joking about this aspect with others—references to criminal activity were an example of dry Australian humour rather than a serious concern that they would be seen as dangerous outlaws.

Whilst the overt nature of the wearable ambient displays was overall positive, further work is needed to improve context awareness. Automatically detecting users' context and changing the behaviour of the display accordingly could be difficult. An alternative is to give users greater manual control over the display, for example allowing the display to be dimmed or switched off while still having physical activity recognised and recorded.

6.3.2 Design

Acceptance and Satisfaction

Users expressed a strong preference for devices to be smaller, less bulky, more comfortable to wear and more attractive. The way in which the device attached to the user's wrist (the device-body interface) was of particular concern.

By using a 3D-printed housing I was able to reduce the size and improve the appearance of the Activthings device over the Activmon device used in the first study. Whilst users still expressed a preference for a smaller, more attractive and more comfortable device, average wear time per day increased from eight hours in the scoping study to ten hours in the final study. This gives confidence to using a rapid prototyping methodology in situations where no suitable commercial hardware is available and there may be the need to iterate rapidly through a number of intermediate interface designs.

Ease-of-Use

I found that battery life, recharging and connection reliability were issues that affected perceived ease-of-use of the devices in the user studies. These issues also contributed to user acceptance and satisfaction.

Due to the power requirements of the LEDs and Bluetooth radios in the wearable devices, and the need to keep them as small as possible, battery life was limited to one day. Users needed to remember to recharge their devices each night so that they would be ready for the next day. Some users felt this was inconvenient and some forgot to charge their devices and therefore couldn't use them the following day.

So that the devices were able to upload users' activity information to a central server (and to enable the group notifications to work) the devices needed to connect frequently to users' mobile phones. Some users found this connection to be unreliable and were frustrated at losing their activity display when the device indicated a dropped connection.

I made improvements in both of these areas in the design of the Activthings device. I produced a 3D-printed charging cradle to make charging more convenient. By having the device perform more data processing on-board I reduced the frequency with which it needed to connect to the user's phone, and I integrated better error handling for dropped connections. This addressed reliability concerns in all but a small number of cases where there were incompatibilities with specific models of phone.

Potential future improvements would be to make the device waterproof, to improve its appearance and to make it more context sensitive. Some users in the second study reported that, knowing the device was not waterproof, they were cautious about wearing it when performing certain activities such as jogging in the rain. Several users reported not wearing the device in situations where the visible lights were inappropriate or the device looked out-of-place. A better looking device, waterproof and with lights that have better brightness control (or could be temporarily disabled) would allow activity data to be collected more often and in a wider range of circumstances, hopefully improving accuracy.

6.3.3 Motivation

Thought and Discussion

It was clear that the individual display engaged users with the task of monitoring their physical activity. Users reported looking at the display often and noticing it change behaviour. Users responded that they cared about the colour of the light and were happy when it turned green, showing a personal, reflective response to the display that went further than basic comprehension.

Users' response to the group display was less encouraging, with users not noticing the ranking display change, feeling they had little control over their position in the ranking and showing a general lack of engagement with the information presented. This was disappointing, as a minority of users did find the display motivated them to engage with their activity levels. As previously suggested, recruiting users who know one another might result in a more positive response and increase engagement.

Participants were prompted to engage in discussions about physical activity with friends, family, co-workers and others who were curious about the device and what the display meant. That the highly visible nature of the display created this explicit social persuasion provides evidence for the theories originally advanced by Lim et al. (2011).

Motivation to be More Active

The broad interpretation of efficacy proposed by Klasnja et al. (2011) considers an intervention to be efficacious if it can be shown that the fundamental properties of the intervention on which behaviour change is premised are operating as expected. I would argue that, with the Activthings device and individual and group activity displays, I succeeded in engaging users in monitoring their physical activity levels. This engagement in monitoring is the fundamental prerequisite for a self-monitoring intervention to influence long-term user behaviour.

Measuring behaviour change directly was not the focus of this research (and, as discussed, Klasnja et al. (2011) warn against this), however users' IPAQ responses and the activity data collected by their devices was informative nonetheless. There was a statistically significant increase in users' self-reported physical activity post-study but there was not a corresponding increase in measured activity levels or self-efficacy for exercise regulation.

The incongruity between self-reported and measured activity could simply have been due to users over-reporting their activity levels post-study. Even if this were the case, and there wasn't an increase in actual activity levels, this would still provide evidence of enhanced mindfulness about physical activity. Users may have simply started noticing the activity they were or were not doing, and this reflection could prove beneficial in the long-term.

Another possibility is that users increased their activity levels immediately that the study began and "plateaued" for six weeks thereafter, sustaining increased activity levels until the end of the study. In this case the negative activity gradients observed for some users may actually have been evidence of those users returning to their long-term average activity after a short increase at the beginning of the study.

That self-efficacy was very stable over six weeks provides confidence that this measure is resistant to short-term variability. It may, therefore, prove to be a useful measure of actual long-term behaviour change if, as argued by Roesch et al. (2010), it is an effective mediator between an intervention designed to increase self-efficacy and actual physical activity.

A future long-term study should involve measuring behaviour change at regular intervals, as well as pre- and post-study. Accurately measuring pre-study activity is difficult as the available methods are not ideal—self report instruments, such as diaries, may be inaccurate, and the use of activity monitors might give an elevated baseline, as users are conscious they are being monitored. The advantage of multiple samples is that it will be easier to spot time-linked trends.

The focus of future work at this point, however, should be to improve the display device and to tune the individual and group display metaphors. If undertaken prematurely, a long-term study could fail simply due to correctable usability issues rather than because the wearable ambient display approach is inherently flawed.

6.4 Contributions

Through this research I have made a number of contributions. I presented the design and evaluation of novel exercise ambient displays and the wearable devices, algorithms and software systems that support them. I showed that wearable ambient displays support both implicit and explicit social persuasion, and that their highly visible nature is a source of motivation for users. Finally, I showed that rapid prototyping technologies, such as 3D printing, are effective for creating high-fidelity prototypes of novel wearable technologies that can successfully gain user acceptance in short-duration user studies.

6.4.1 Exercise Displays and Display Devices

As discussed in Section 2.2, there are many existing wearable devices that allow users to monitor their physical activity. These devices, however, require the user to consciously engage with them by pressing buttons, using gestures or checking apps. They fail to fully realise the calm computing vision of Weiser and Brown (1996)—that by integrating information into the user's environment in a truly ambient way we can empower and encalm users.

The wearable ambient display devices I developed had a persistently visible, colour display, to provide users with information at a glance. Users could engage with the display easily and at any time, without the requirement that they be undertaking some other activity (such as checking their phone or computer). The individual and group activity displays that I developed took full advantage of colour and light, using flashing and shifting colours to convey information in an eye-catching way.

Activthings' continuum individual display, where users were challenged to increase their weekly average activity over the long-term trend, was a novel exercise display. The original design, showing daily activity against a daily goal, was similar to existing displays but appeared to be too inflexible. The continuum display attempted to smooth out short-term variability and provide a more stable activity metric to users.

Also novel were the flashing and ranking group activity displays. These employed an ambient information paradigm to provide users with a near-realtime assessment of their activity levels compared to others. Whilst past research has explored the use of ambient displays to convey group activity information (Lin et al., 2006), I showed that this paradigm was transferrable to wearable ambient displays.

A further aspect of this contribution was the development of the distributed software system and algorithms that supported the individual and group displays. This included algorithms to create sliding-window activity averages (with median imputation), to automatically calculate users' weekly goals, to determine when users were being physically active (for the flashing group display), and to create fair comparisons between users (for the ranking group display) (Section 4.2). I intend these algorithms to be reusable by other designers in the field.

6.4.2 Implicit and Explicit Social Persuasion

Expanding on the work of Consolvo et al. (2006), I proposed social persuasion could be implicit, where users are presented with the activity information of others, or explicit, where users are engaged directly in conversations with others about physical activity.

I demonstrated with the flashing and ranking group displays that wearable ambient displays could enable implicit social persuasion. Existing commercial wearable devices focus on displaying individual performance and relegate social information to a supporting website or app. By presenting this information on the wearable device itself, in an ambient way, I made it more glanceable, overt and accessible.

Whilst explicit social persuasion was previously proposed by Lim et al. (2011), they were unable to demonstrate the effect in practice. The use of a non-ideal form factor (a foot-mounted device) and a rough prototype device hampered their study—users found the device strange and were uncomfortable with the attention they received. With a study size of only 18 users over a duration of two weeks, with only a quarter receiving the active intervention, their findings were limited.

In contrast, at least some users in the Activthings study commented that the highly visible nature of the Activthings device, and their interactions with others as a result, were positive aspects of their involvement. Although there were some concerns about the appropriateness of Activthings in certain contexts, it appeared to be less awkward and unwelcome than was the case for the Pediluma device of Lim et al. (2011).

6.4.3 Rapid Prototyping Technologies

In the past, Human-Computer Interaction (HCI) researchers have had limited options when prototyping wearable devices. Commercially-available devices may be expensive or too difficult to modify for the intended task. Construction of fully-working prototypes was time consuming and expensive. A simple but limited approach was to not construct a prototype at all, but use paper prototypes or design sketches. If the system could be partially implemented then Wizard of Oz techniques could be used to simulate missing elements.

In the past few years, with the wider availability of rapid prototyping technologies such as 3D printing, researchers' options are greatly improved. A rough sketch of the housing for a new wearable device can be rapidly converted into a 3D model and produced in sturdy plastic. Development boards such as Arduino allow the rapid creation and testing of embedded software and hardware. Quick-turn printed circuit board (PCB) fabrication and assembly services can then be used to create electronics assemblies for actual prototype devices.

The use of 3D printing is not novel—my contribution is to show that it is particularly applicable to wearable computing research. The appearance, comfort and usability of wearable devices is more important than other forms of computer hardware due to the intimate connection with the user's body. I showed that Activthings' 3D-printed housing, whilst not addressing all user concerns about size and appearance, was nonetheless successful in gaining user acceptance over a six week study, with average wear time increasing over the previous hand-constructed device.

Rapid prototyping fits particularly well in the field of HCI, where a common technique is to iterate through a number of different designs, to find one to which users respond and find most usable. When I discovered that charging was a concern to users I quickly created a 3D printed charging cradle to simplify the process. This ability to rapidly produce new devices or variants is invaluable to the researcher, allowing them to quickly "troubleshoot" their designs in response to user feedback without the need to undertake time consuming re-design and re-testing.

My results give confidence for the use of 3D printing to create rapid prototypes of wearable devices for deployment in short-duration user studies. Using this technology researchers can clear the initial hurdle of producing prototypes that are "useful enough" to collect initial data, saving time and money that can be later spent creating better prototypes when the ultimate design becomes clearer.

6.5 Limitations

The validity of the results I obtained are limited by both my choice of methodology and the way in which I employed that methodology. Following the advice of Klasnja et al. (2011), I chose a methodology that focussed mainly on the design aspects of wearable exercise ambient displays. I aimed to show that the active elements of my self-monitoring intervention were present and operating, rather than to demonstrate behaviour change directly. This limited my ability to draw conclusions about the direct efficacy of the display and device in changing users' exercise behaviours.

Whilst the Activthings user study had a relatively large number of participants in terms of comparable studies in HCI, my use of eight different conditions meant there were anywhere from two to five active users in each condition. This limited my ability to draw conclusions about any particular condition from quantitative results. For example, it appeared the low red threshold, low goal individual display was preferred by users over other individual display variants, but it was not possible to conclude that this variant was optimal, as only five users were assigned to that condition. I was able to collapse conditions together in order to perform analyses on larger numbers of users, however these collapsed groupings were not truly homogeneous.

The various design differences could have been better separated to test each in isolation. For example, I could have assigned ten users to a high goal condition and ten to a low goal condition, leaving red line settings the same. There could also have been other displays or variations that I didn't test that would have worked better. For example, different red and goal line settings for the continuum display, or a different ranking algorithm for the group ranking display. More preliminary work with users, determining which properties they found important, might have better guided my selection of these conditions.

Some limitations were inherent in the way that I employed the chosen methodology. In Section 4.2.10, I discussed the way in which I recruited users for the Activthings user study. Whilst my recruitment methods were straightforward they likely introduced an element of bias, both due to the recruitment methods I used and the way in which I allowed users to self-select.

Having participants self-select would have resulted in a bias toward participants who were particularly receptive to, or interested in, the idea of increasing their physical activity or the wearable device being used. This would tend toward producing results which would over-state measures of satisfaction with the intervention and device. Asking users to wear devices every day may also have resulted in usage data that overstated satisfaction.

Although I didn't directly ask users how they heard about the study, based on the timing of sign-ups the majority joined after seeing it promoted on the University's website. At least some of these users were University staff members and students, who may have had a similar socio-economic background. This limited my ability to generalise my results to the wider community.

I attempted to control for as many variables as possible, for example providing users with only an ambient display and not a smartphone app, and recruiting participants who didn't know one another into group conditions. This may have produced results that understated user engagement and satisfaction that would have otherwise been evident had the study been conducted with these biases included. Some users may have been more satisfied with the Activthings device had they been provided with an accompanying smartphone app, and others may have engaged more with the group display had the other users been people they already knew. Lower satisfaction or engagement could also have resulted—this may be a focus for future research.

The measurement instruments and methods I used could also be improved. Although I attempted to show the Activmon and Activthings devices and algorithms adequately discriminated between physical activity and sedentary behaviour, I tested these mainly on myself and with a limited range of activities. Further work on validating these algorithms with more users and more activity types, prior to using them in a study, would have given greater confidence in the activity data recorded.

6.6 Future Work

I have shown that wearable ambient displays are effective in conveying information to users about their level of physical activity, encouraging them to think about and discuss it and, for some users, to be more active. Further work is required, however, to develop the individual and group ambient displays, the wearable ambient display device and evaluation methodologies prior to undertaking a long-term study to demonstrate behaviour change.

One important line of enquiry would be to explore different individual activity displays. This could involve using different information presentation metaphors as well as varying the information presented. Despite my arguing for the traffic light metaphor for individual activity, there are other metaphors that might increase users' willingness to engage with the display. Whilst the "continuum" activity display used in the second study appeared to work well, further work is needed to better determine ideal goal and red line settings. Further, there may be other types of information that could be presented alongside or instead of physical activity, for example discrete variables such as number of exercise sessions or breaks taken from desk-based work.

Given that socialisation is an important motivator to people to become more active (Ryan, Frederick, Lepes, Rubio, & Sheldon, 1997), undertaking a more thorough evaluation of the group interface will be an important future priority. It was unfortunate that I did not see a stronger response in the Activthings study, as users did not seem to be motivated by seeing anonymous others, and some from each group left the study prematurely. In a future study I could recruit people who already know one another, in the hope that existing social dynamics would enhance engagement and reduce the drop-out rate. Another option to address drop-outs would be to "overload" each group with more than five users, although only four others would be displayed on each user's device at a time.

In future studies I could explore different group activity displays. The ranking display could be compared with the flashing notification from the first study to determine which is more effective at engaging the attention of users. The period over which users are ranked could be further tested to determine whether some value between the one week and three hour periods I used is more effective.

Some users in the Activthings study expressed a desire for more information beyond that which was presented on the ambient display. For the purposes of this research I deliberately chose not to provide that information in order to test the ambient display in isolation. In future I would combine the two, thus providing users with a source of more detailed information they could access on a discretionary basis. For example, if they wanted to track historical trends in detail or to "drill down" into information about a particular workout.

The important topic of goal-setting should be re-visited. There is merit in having goals set automatically for users who are not motivated to set them themselves—this lowers the barrier to people engaging in self-monitoring and could be particularly helpful for users with a low level of numeracy or health literacy. However there may be no single approach that will work for all users.

An alternative would be to allow users some degree of control over their goals, whilst still generating them automatically. In an initial design for the Activmon system, I had proposed that users be able to provide feedback in the form of "harder goal", "easier goal", or "freeze goal to present level" (Burns et al., 2011). This idea could be implemented for Activthings with the addition of another control for the red line, to allow users to adjust the amount of sedentary behaviour that is required to turn the display red. There is also the question of whether automatically generated goals should adjust downward from one week to the next when users have failed to meet the previous week's goal, and whether this keeps users motivated or works against continual improvement.

I argued that it is important to give users feedback about their behaviour as soon as possible so that they are encouraged to continue engaging with the device (Section 5.2.1). However, the approach Activthings took of calculating a goal with as small an amount of user data as possible was not well-received, with some users being left with inaccurate goals for the following week. A future device could extend the learning period to one week (as was the case with the Activmon device) and specifically examine the benefits of more accurate goal setting against the negative effects of participant boredom or disengagement.

In terms of user recruitment, I could draw participants from either a broader or more constrained user population. A study involving participants who are more representative of the Tasmanian or Australian community would demonstrate how widely applicable the technology could be. If existing government approaches to tackling obesity, such as education and coaching, aren't effective enough, there may be the need for more interventionist public policy. A simple, cheap and widely useful wearable ambient display device could be subsidised by the Federal Government, or even provided for free, through the Medicare system. Evidence of broad applicability would support the case for such a move.

More narrowly targeted studies could focus on specific groups such as the obese or "super-obese" ($BMI \geq 45$), or those from lower socio-economic groups. As I have argued previously, it could be that an ambient display interface is more useful and effective for people with lower literacy, numeracy and health literacy than a more complex interface. A device employing an ambient display could make a useful addition to an existing medical treatment program for obese or super-obese people.

While 3D printing allowed me to create a device that was smaller and more attractive than my original hand-constructed prototype, users still wanted it to be smaller and more aesthetically pleasing. Future prototyping efforts should be directed toward addressing these concerns. This is more than simply an engineering issue—I have shown that the appearance of the device has clear implications for user acceptance and the environments in which users will wear it. For Activthings, the size, bulk and comfort (particularly the way the device attached to users' wrists) was significant.

This in turn affects the amount and quality of information collected, its accuracy and therefore the effectiveness of the device in prompting behaviour change.

In appreciating that people's choice of what to wear is a very personal decision, I could offer users a range of different designs or colours and allow them to choose the one that they felt was most attractive. Alternatively, if it is impractical to offer more than a few designs, I could encourage users to paint or decorate their devices as a form of individual expression, in the hope that this would create a sense of ownership that would encourage them to wear their devices more often.

The highly visible nature of wearable ambient displays can be useful, in that users are prompted to engage in conversations with others about the information presented. Nonetheless there is a need to make the Activthings device more sensitive to users' contexts. Automated context awareness is the focus of a great deal of research in ubiquitous computing, though computers are yet to truly understand human social conventions and expectations. Possible alternatives are to allow the user to nominate particular times or locations that the display should be dimmed or disabled or, following the approach championed by Rogers (2006), to allow users to exercise their own intelligence in switching the display on, off or to a dimmed state as they see fit.

Klasnja et al. (2011) argue that longitudinal studies should still be the ultimate goal when evaluating the efficacy of a behaviour change intervention. A series of small, short-duration user studies are useful in understanding which components of an intervention are most effective (and in allowing them to be tuned) but there is still the need to show behaviour change in the long-term. A study over the course of a year or longer would be an eventual goal.

Ultimately, behaviour change must come from within and users need to be willing to engage with the information presented and try to be more physically active. This would be my hope for wearable ambient displays for the future—that they could act as an efficient and effective tool to assist people to use their own agency, to change their behaviour for the better.

Appendix A

Additional Result Graphs

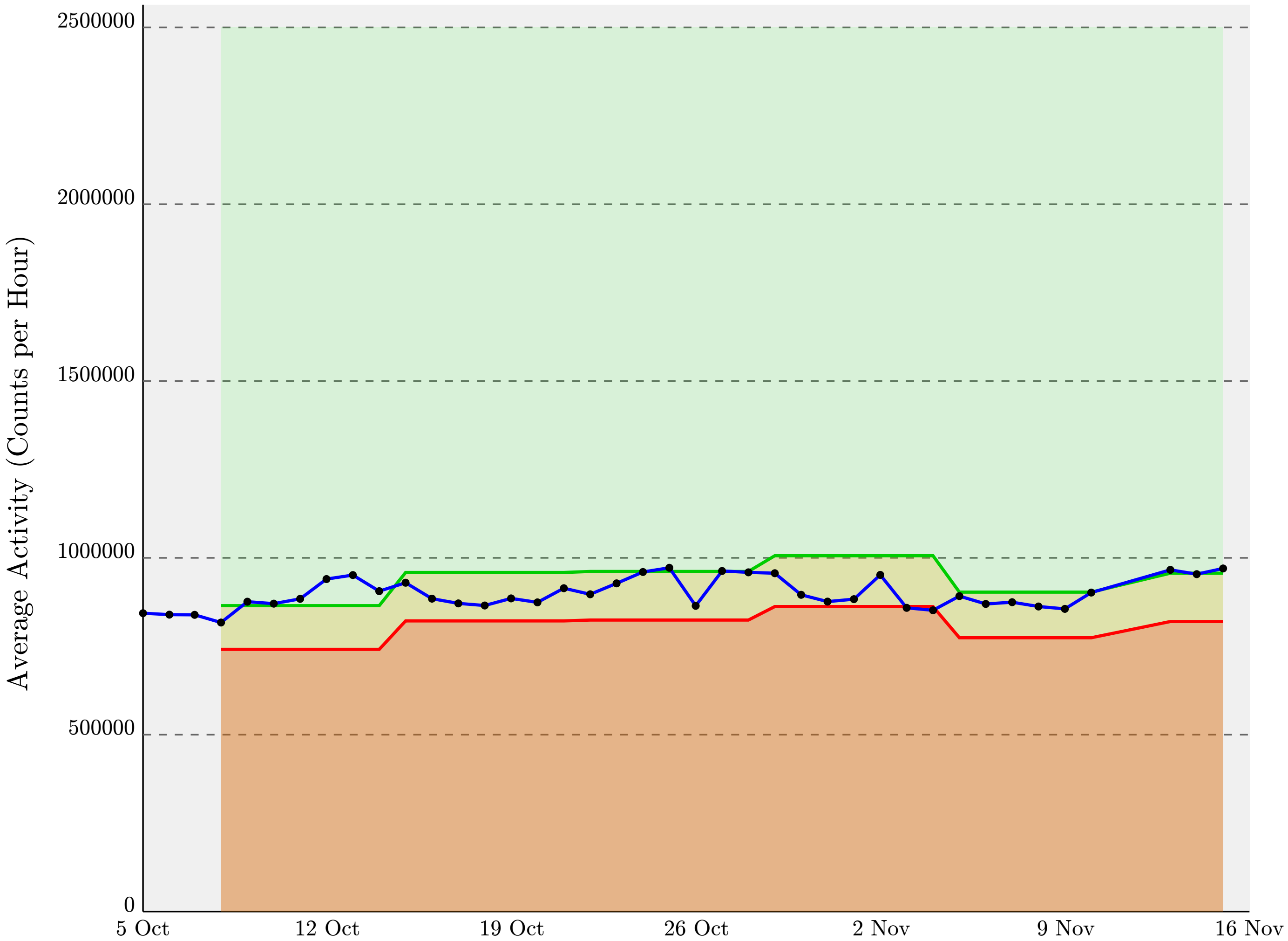


Figure A.1: Example of a user with consistent activity levels (A600)

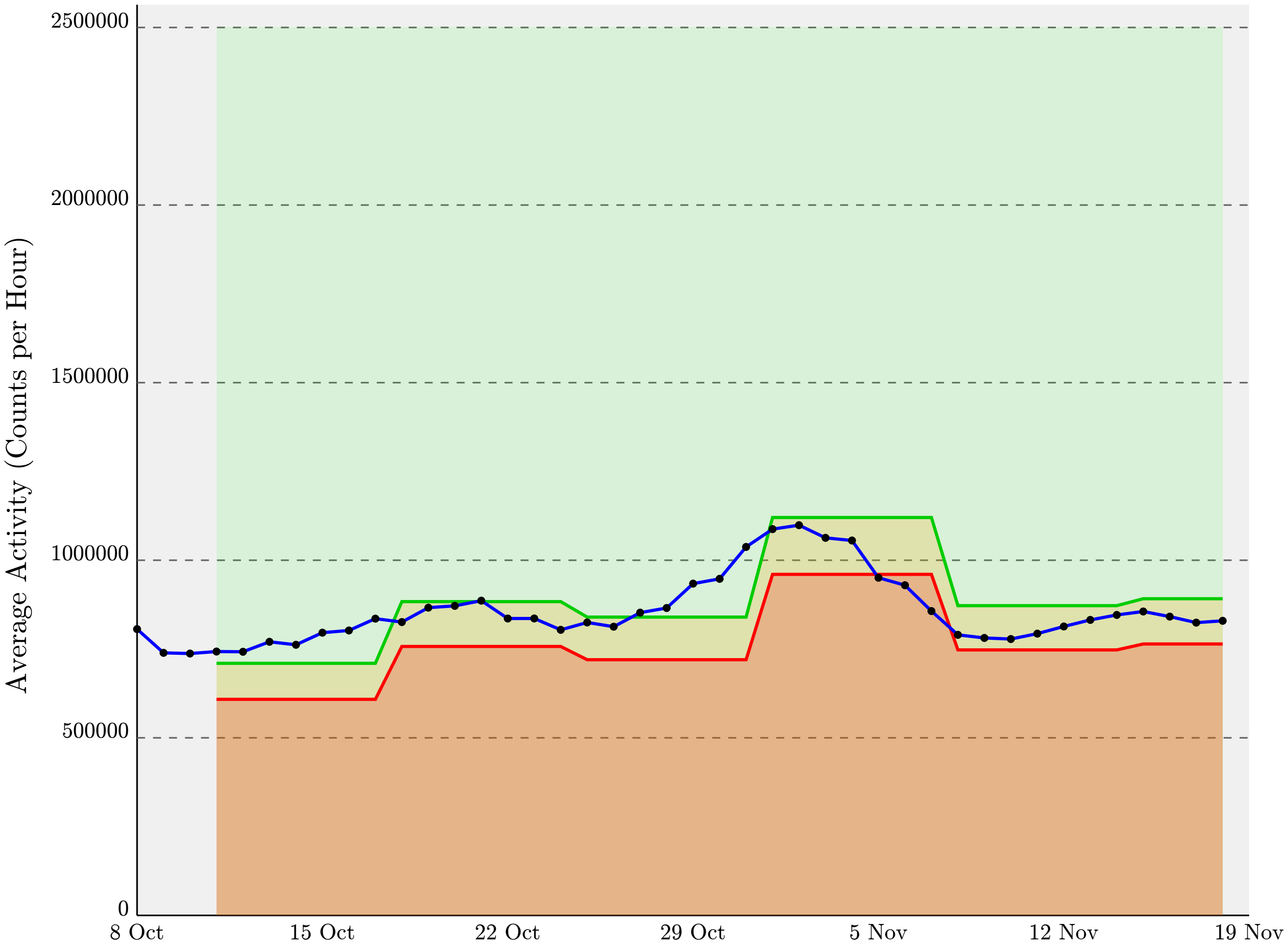


Figure A.2: Example of a user increasing their activity levels (A909)

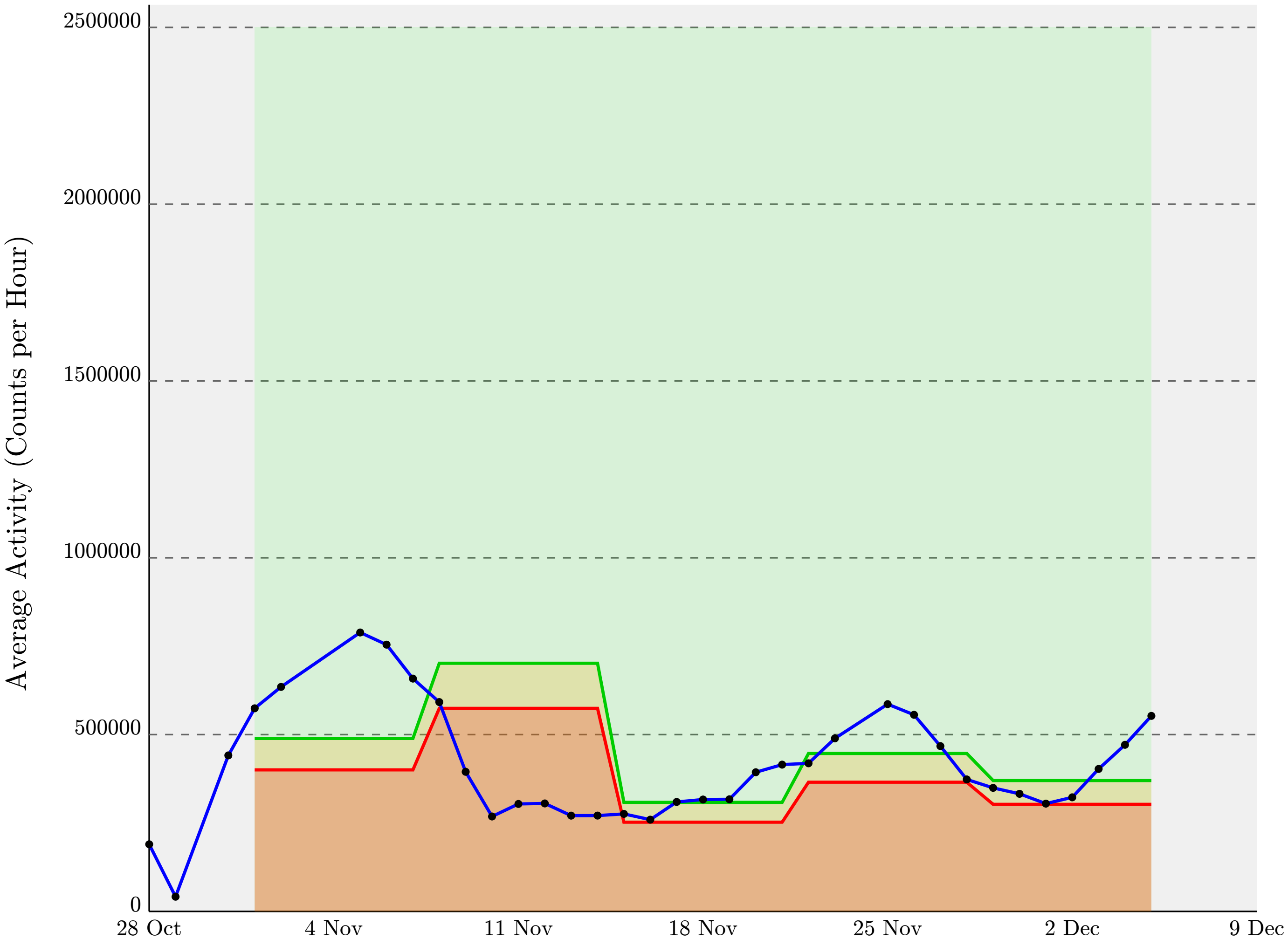


Figure A.3: Example of a user with volatile activity levels (A152)

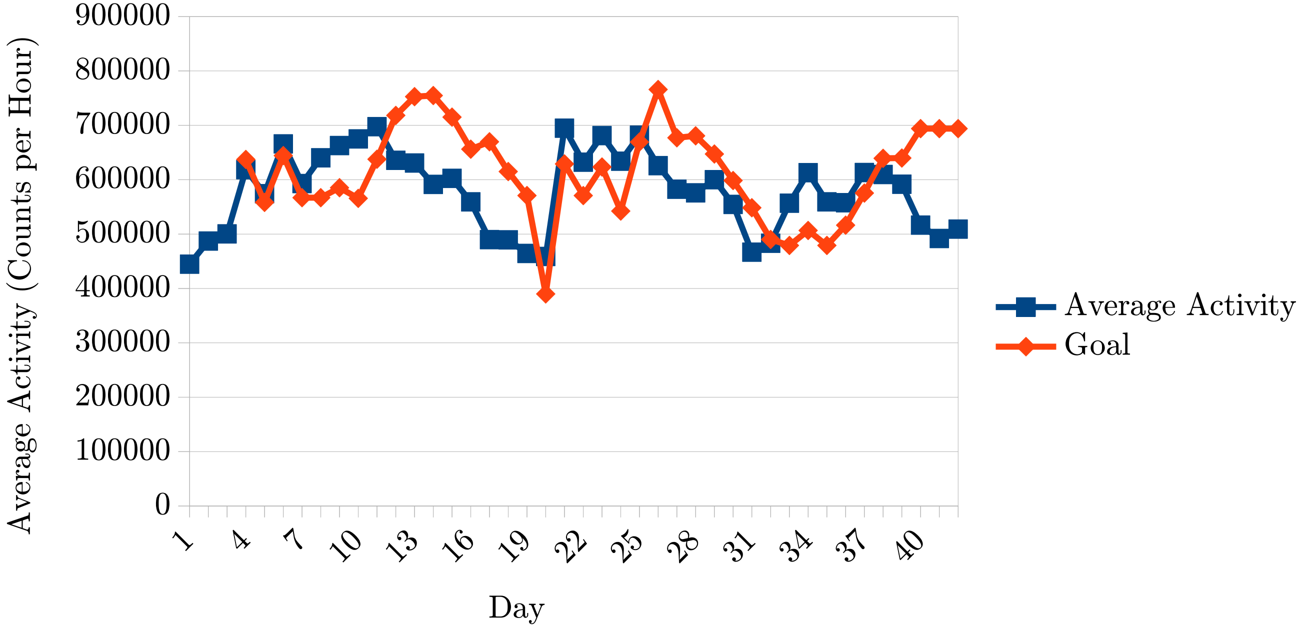


Figure A.4: Average Activity per Day—“High Goal” Conditions

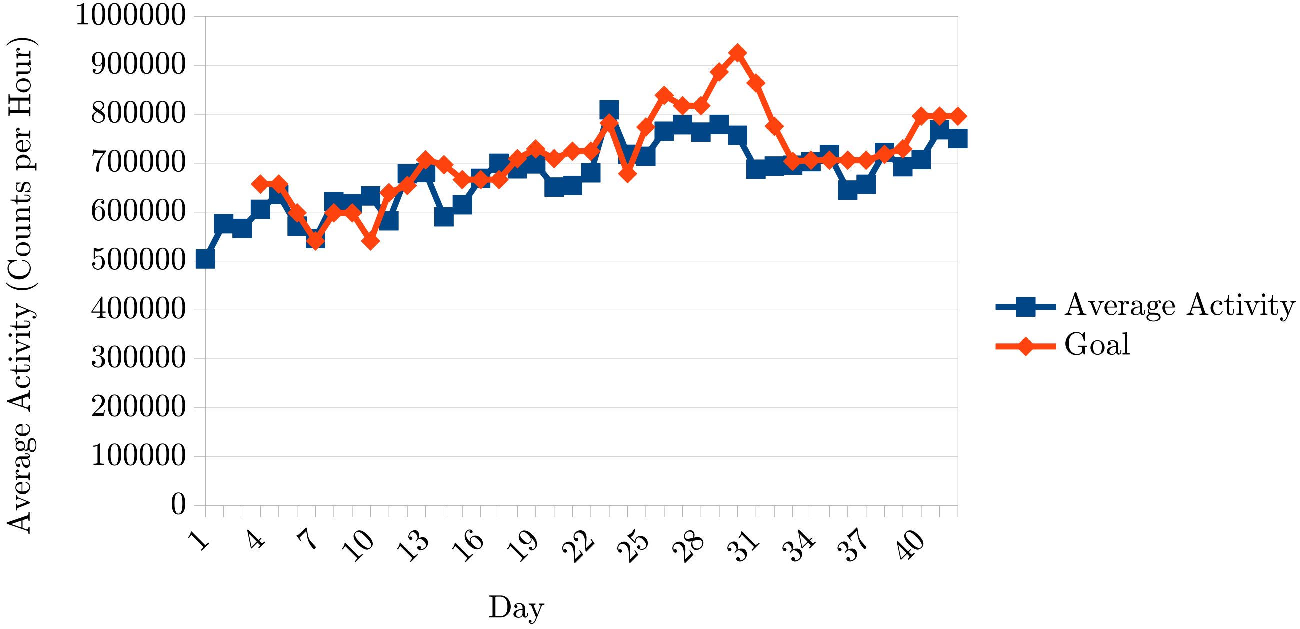


Figure A.5: Average Activity per Day—“Low Goal” Conditions

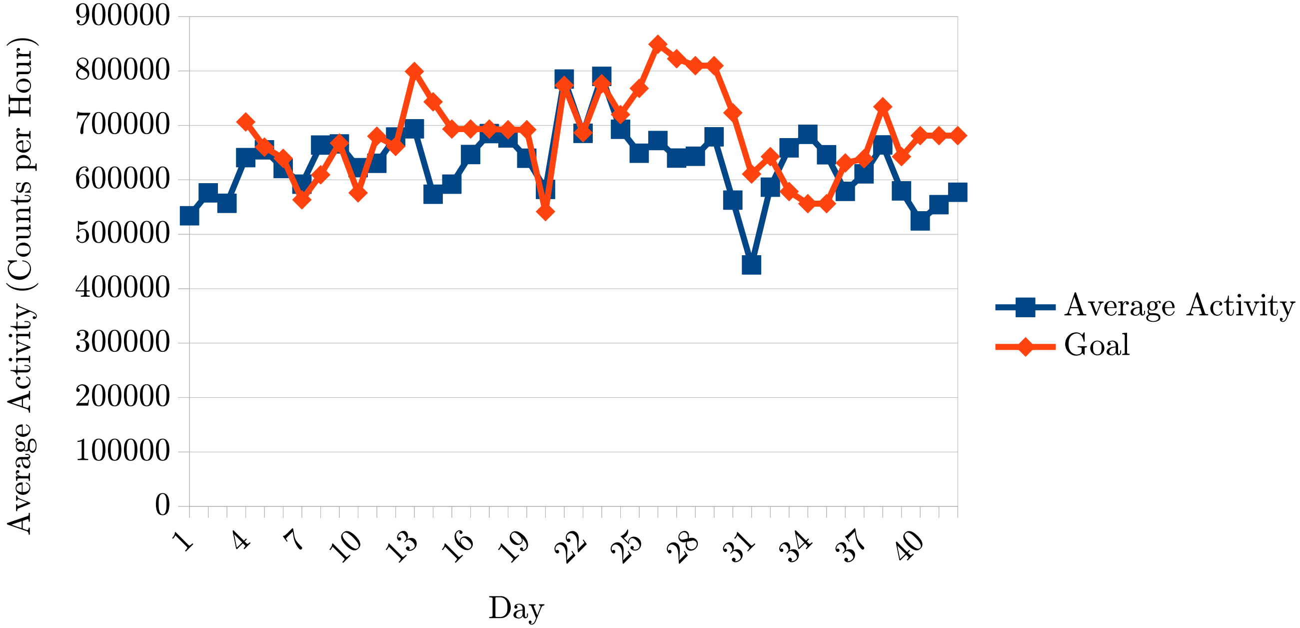


Figure A.6: Average Activity per Day—“High Red Threshold” Conditions

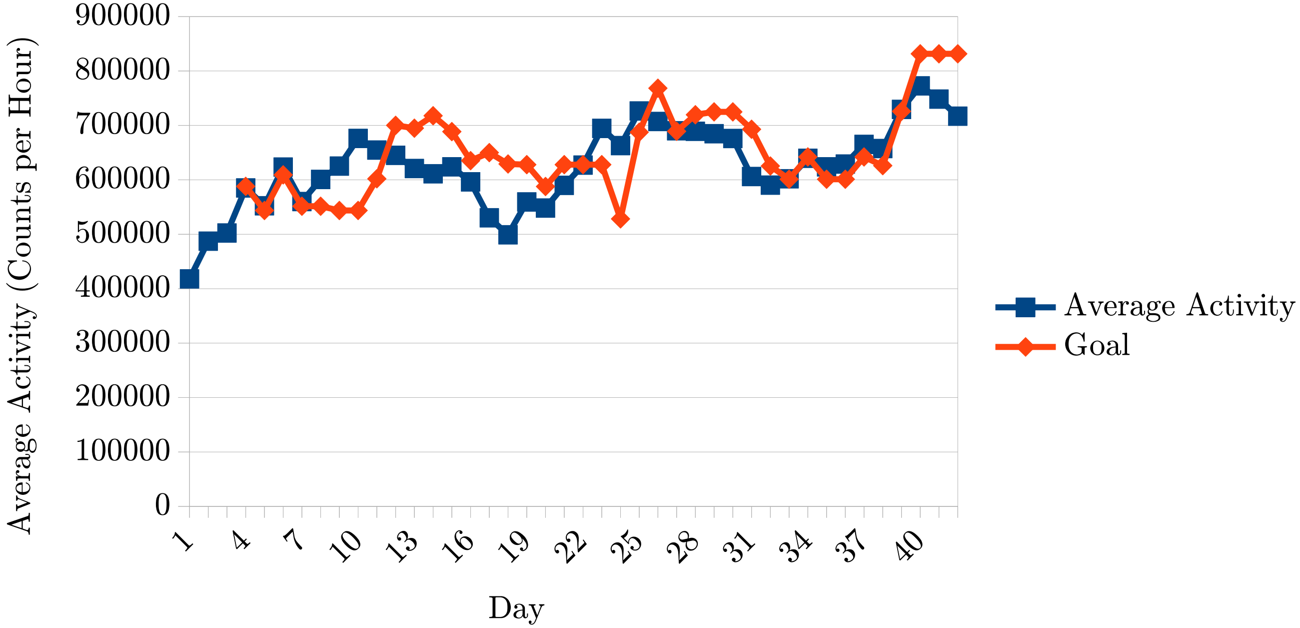


Figure A.7: Average Activity per Day—“Low Red Threshold” Conditions

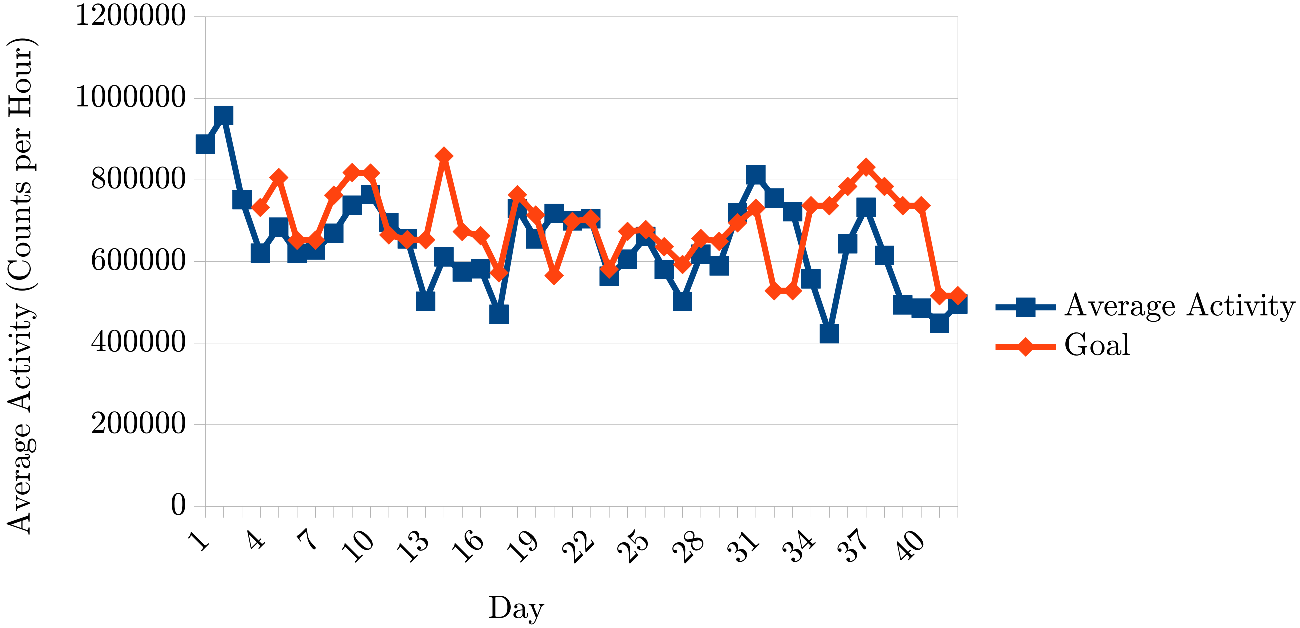


Figure A.8: Average Activity per Day—“Combined” Conditions

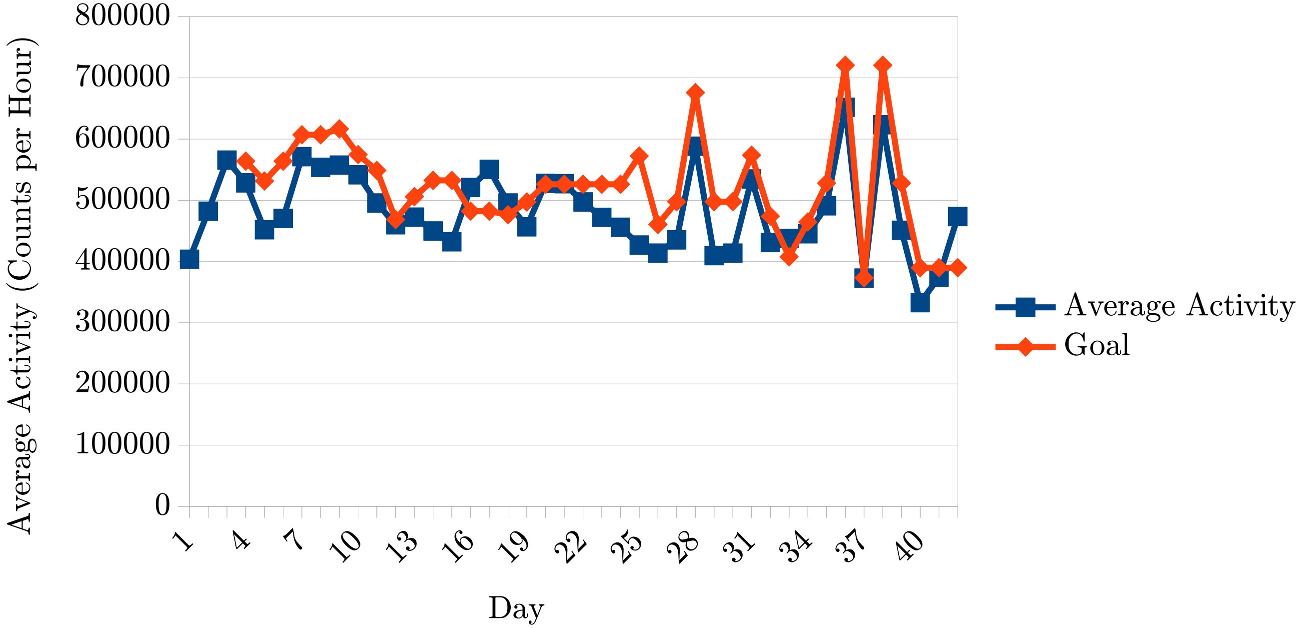


Figure A.9: Average Activity per Day—"Group Only" Conditions

Appendix B

Algorithm Validation

After writing the accelerometer processing algorithms for the Activmon and Activthings devices, I assessed their accuracy by engaging in sedentary and physical activities and analysing the results produced.

B.1 Activmon Algorithm

I wore the Activmon device while physically active (walking at a moderate pace), and while sedentary (sitting at a computer), collecting 30 minute data sets for each type of behaviour. Comparing the activity counter value after 30 minutes for each type of activity, physical activity produced a significantly larger value than sedentary behaviour (Figure B.1).

Comparing activity rates between the two data sets, physical activity was easily discernible from sedentary activity. The average 15-second rate of change for physical activity was significantly higher ($mean\frac{\partial a_{physical}}{\partial t} = 9.46 \times mean\frac{\partial a_{sedentary}}{\partial t}$) than for sedentary activity (Figure B.2). It was, therefore, possible to detect physical activity by applying a threshold of three times the average of activity counter rates.

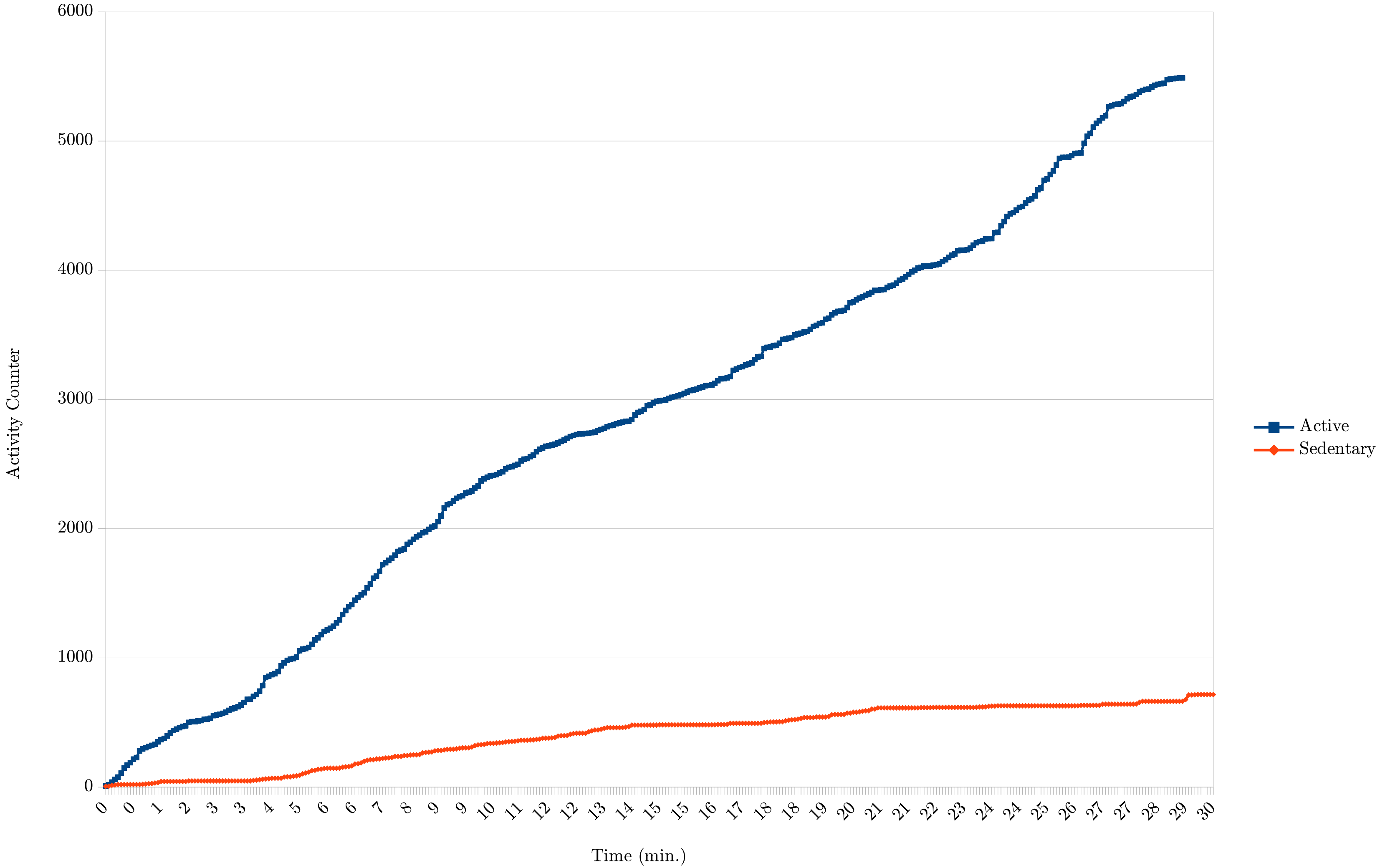


Figure B.1: Activmon Activity Counter Values for Sedentary and Physical Activity

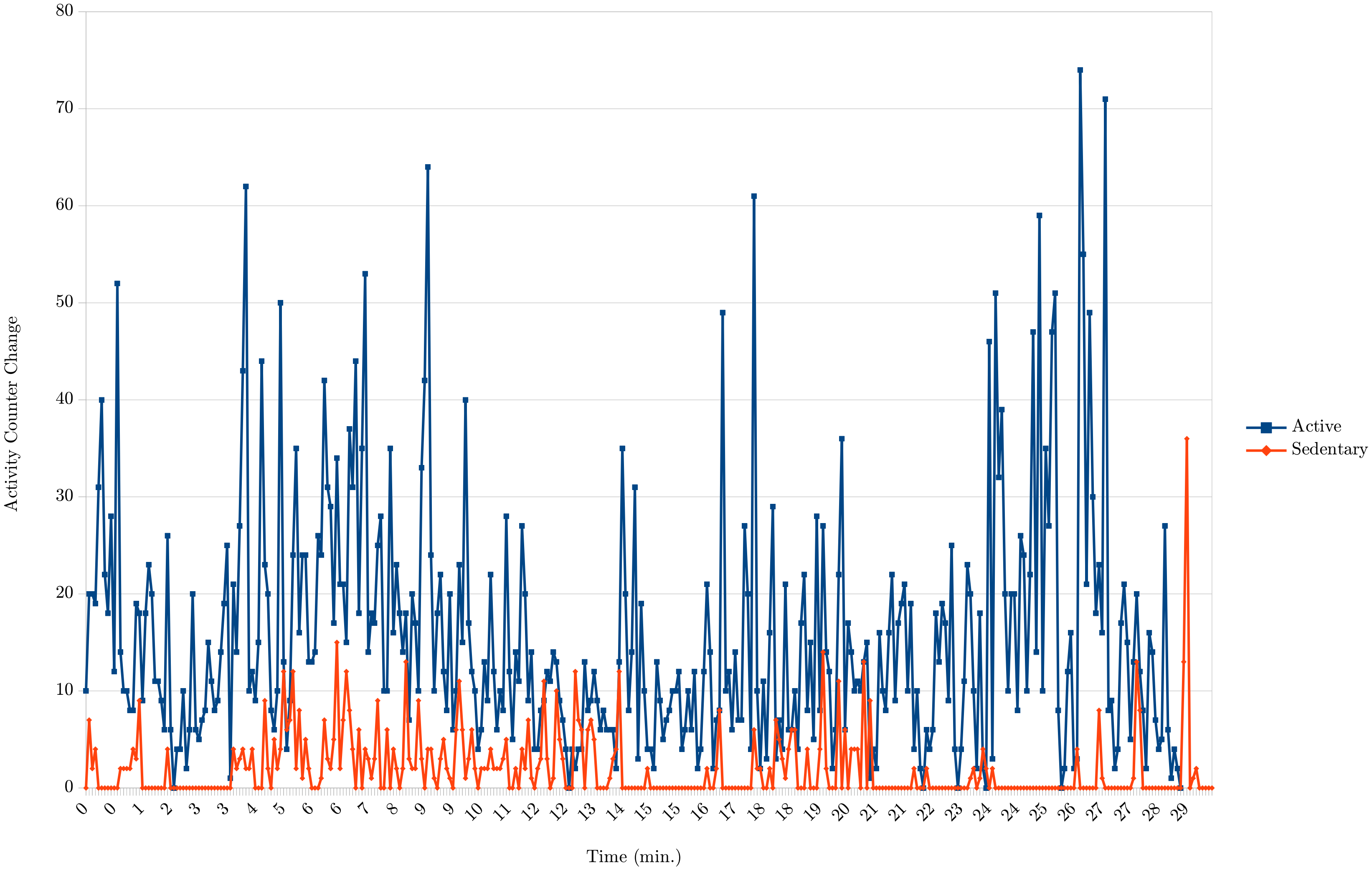


Figure B.2: Activmon Activity Counter Rates of Change for Sedentary and Physical Activity

I then collected a larger data set, wearing the device for approximately twelve hours whilst engaging in both physical activity (walking) and sedentary behaviour (sitting down, eating, watching television, and using a computer). The individual activity display appeared to change in proportion to my physical activity as expected. Looking at a graph of a_i against time (Figure B.3), there was a clear delineation between periods of physical activity and sedentary behaviour. I repeated this test over a further eight days.

As a simple test of the group activity display, I had a colleague wear the device, and I wore another, over a period of ten days (of which both were worn simultaneously over seven of those days). Again, I noted that the individual activity display appeared to change in proportion to my physical activity, and a graph of a_i against time (Figure B.4) showed a clear delineation between activity types[1]. My colleague reported seeing her device flash at times coinciding with my being physically active, and I noticed my device flash when she was physically active.

[1]Some very large activity rates have been scaled off the graph

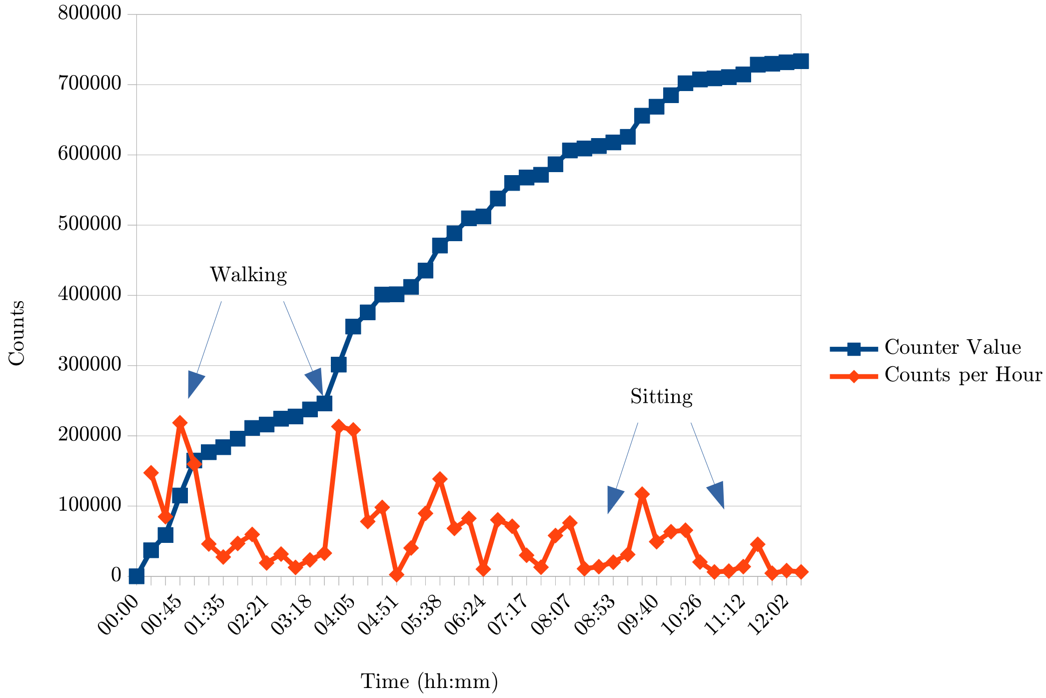


Figure B.3: Activmon Activity Counter Values and Rates of Change Over Twelve Hours

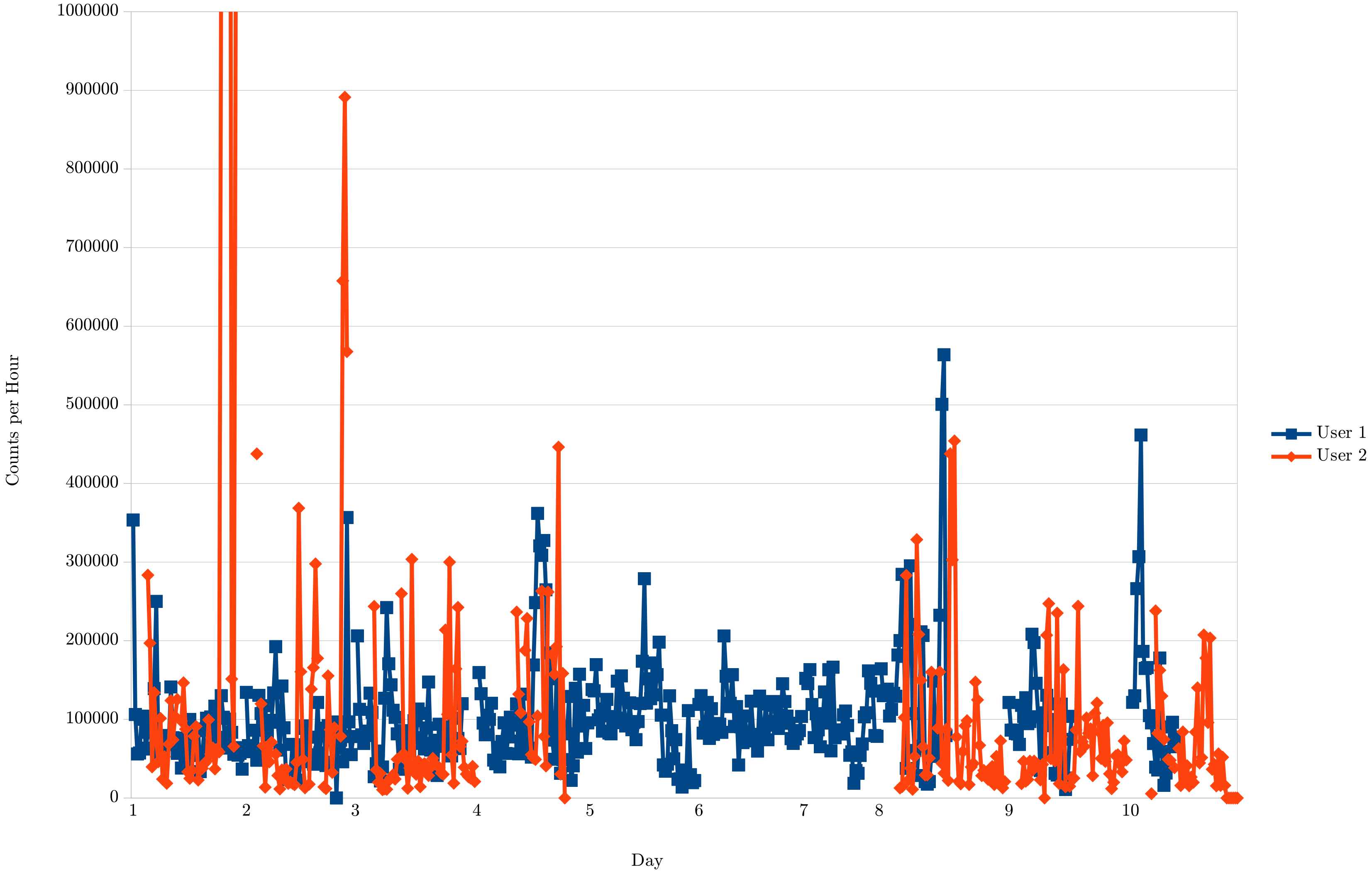


Figure B.4: Activmon Activity Counter Rates of Change for Two Users

B.2 Activthings Validation

In order to validate the Activthings device and new individual display, a colleague and I wore the device for approximately three weeks in a variety of sedentary and active situations (Figures B.5 and B.6, respectively). I noticed the individual activity light change appropriately, both when I engaged in exercise and when I had been sedentary for some time. The new ambient display appeared to be more resistant to short-term volatility—it was challenging to make the light turn green (a single exercise session was inadequate), and the light turned red slowly over days of inactivity.

I observed the group display changing in response to my activity levels in comparison to those of my colleague. When I was more active, her light would be displayed below my individual light, and when she was more active, her light would rise above mine. In order to test the other group display lights, I inserted simulated data into the server database to represent other users and observed that the correct group ambient display was generated.

The device seemed comfortable to wear over long periods of time and was not unduly irritating. It did prove better to leave the strap slightly loose, however, to avoid the Velcro marking my skin. The band did not appear “sweaty” when exercising. The majority of my daily exercise involved walking on a treadmill, and to avoid tripping I usually held the handrails with both hands. Obviously this meant the device was not able to register that exercise, so I experimented with having at least one arm (on which I was wearing the device) free to move. I also experimented with wearing the device on my ankle during walking and on my wrist at other times. Having my wrist move freely worked well, as did wearing the device on my ankle. With the latter approach, however, I then received less credit for the same activity performed whilst wearing the device on my wrist, as the accelerations it recorded were less intense at this location.

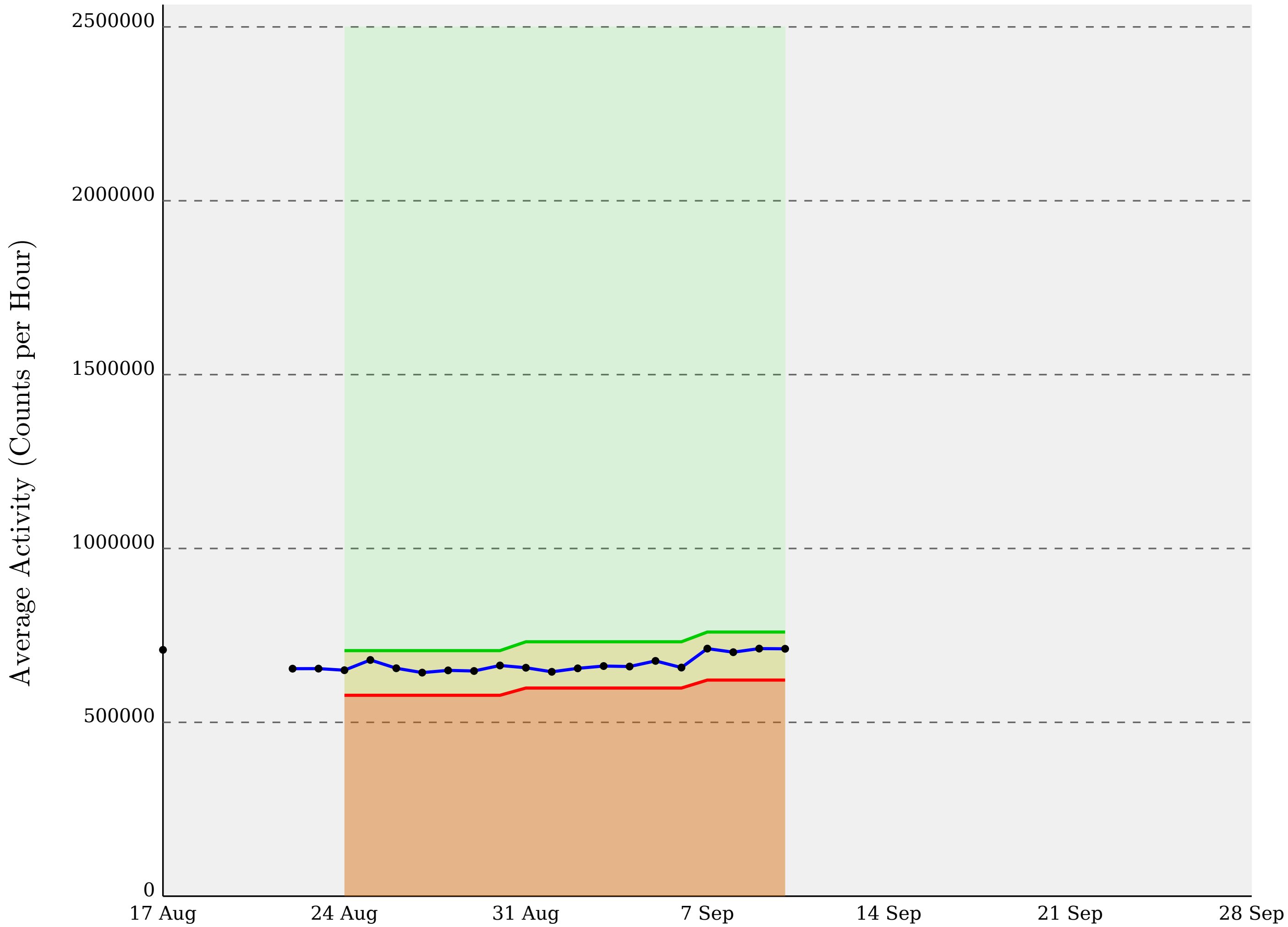


Figure B.5: My Colleague's Daily Activity Average and Goals Over Three Weeks

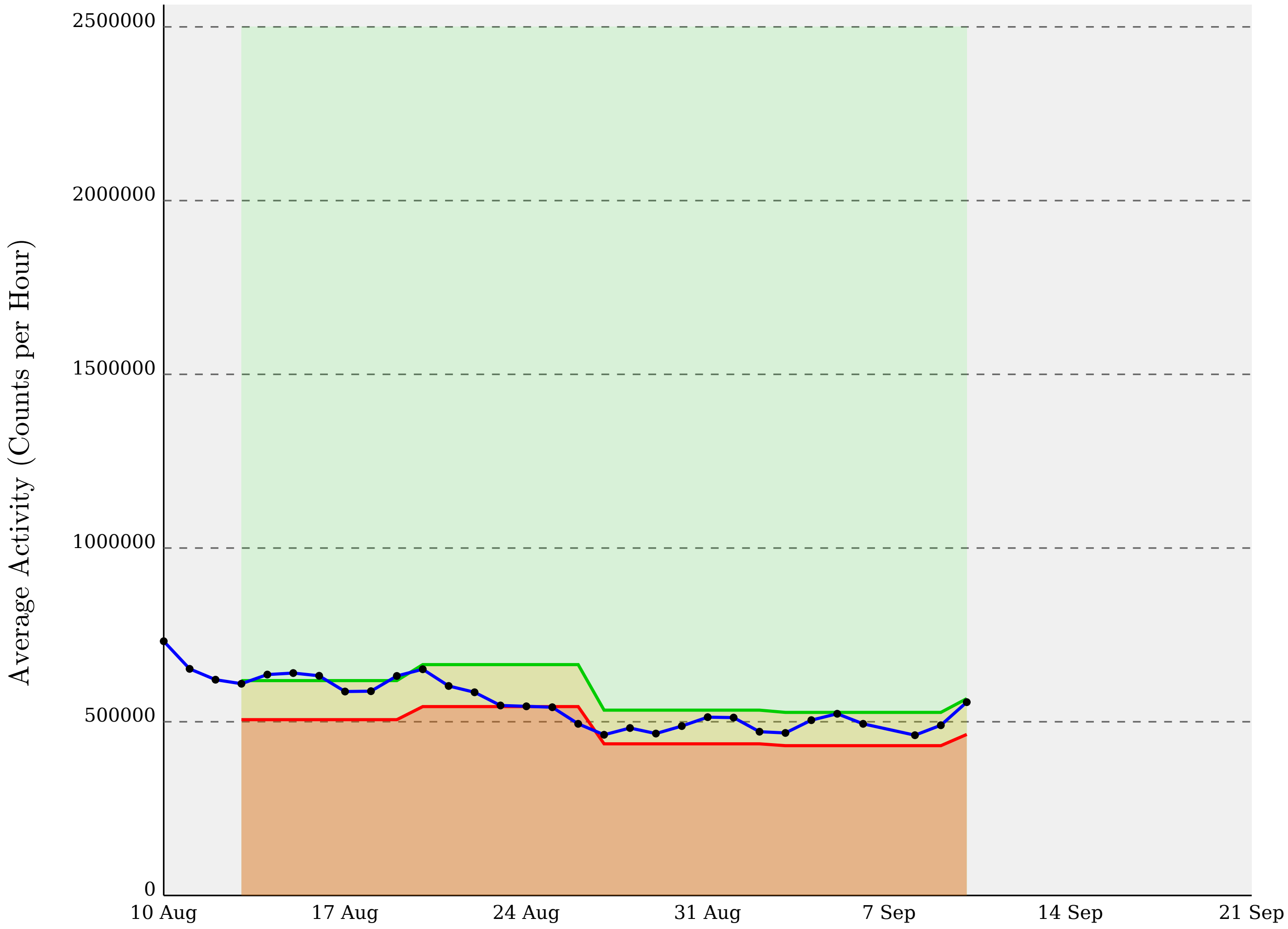


Figure B.6: My Daily Activity Average and Goals Over Three Weeks

B.3 Discussion

These results supported the use of the Activmon and Activthings activity algorithm as a rough representation of physical activity. There was a marked response to physical activity that delineated it from sedentary behaviour.

My goal was always to distinguish between physical activity and sedentary behaviours and determine the time users engaged in each, not to precisely determine the user's energy expenditure, form of physical activity, distance travelled or steps walked. This inability to determine the magnitude of physical activity is, however, an obvious limitation of the approach. My algorithms may fail to detect moderate physical activity, or may not adequately credit intense physical activity.

Validation using only myself and one other person was also a limiting factor. It may have been the case that the particular types of physical activity we engaged in were not generalisable to others, and as a result their physical activity may not have been properly captured.

I would expect that other exercise ambient display designers could reuse this simple approach, in situations where they wanted to quickly transform accelerometer data into a representation of physical activity. A better approach, however, might be a community collaboration to create a free and open-source activity classifier algorithm, open to independent scrutiny and able to be reused across a range of research and devices. This was outside of the scope of my research, however.

Appendix C

Activthings Technical Description

This appendix serves to provide the reader with additional technical details about the design and construction of the Activthings device and back-end server software discussed in Chapter 5. The information in this appendix is not required to understand and appreciate the results and contributions presented in the rest of the thesis, and is therefore presented separately. However, I hope that it might be of some interest or use to researchers wanting to gain a deeper understanding of the prototype device used to collect the results presented, and to perhaps provide a template that could be copied for future research.

The circuit schematics and PCB layouts presented at the end of the chapter are licenced under the same terms as the rest of this document, and digital copies are available from the author on request. For brevity I have not reproduced any source code, however I would be willing to consider releasing it under an appropriate licence should the reader be interested in acquiring it.

C.1 Hardware Design

As discussed in Chapter 4, at a high level the Activthings device needed to have:

- An accelerometer to track the wearer's physical activity
- A multi-colour light emitting diode (LED) to create an ambient display
- A wireless radio to upload activity data to a central server and download activity data regarding other users (to create a group activity display)

At the heart of the device I chose to use a microcontroller. It needed to perform well running at low voltages, be clocked at a high speed with low power use, and have plenty of IO pins. I needed the microcontroller to interface with all the components above, but also to detect when external power was connected, detect when the battery was charging, and sense the battery voltage (in order to estimate its state of charge).

The power usage of all of these components was critical, as the best way to reduce the overall size of the device was to use a small (and therefore low capacity) battery. I needed to design with power consumption in mind from the very beginning. For example, I chose low-power peripherals and ensured I could switch off power-hungry components under software control when they weren't needed.

In order to communicate with a wide range of phone models, Activthings needed to support a number of different Bluetooth profiles. The Bluetooth module and software I had used with Activmon only supported the Serial Port (SPP) and Dial-up Networking (DUN) profiles. Mobile phone manufacturers had started to move away from these legacy profiles to the more sensible Personal Area Networking (PAN) profile. There was a need to support this new profile for mobile operating systems such as iOS and Android 4+, as well as the older profiles for Android 2, Symbian and other "feature phones".

I wanted to write extensive logging code, so that Activthings could use its memory to store a record of what it had been doing. The purpose of this was two-fold—it would be critical for debugging purposes that I have sufficient information to track down faults, and some of the data (for example, details on battery life or connection reliability) might be of interest to my research. Also, there was the need to cache activity data between server connections.

With the Activmon device I only needed to upload one activity rate per connection, every 15 minutes. The Activthings design called for caching activity rates and performing a batch upload every hour. I would need a new client-server protocol to allow multiple samples to be uploaded to the server, potentially split across multiple packets, and to allow the server to send ranking information to the device. I also felt it would be useful to have an over-the-air firmware upgrade facility, to allow the server to provide new firmware to the devices over the Internet. If I deployed a number of devices as part of a research study and then found a software bug, I would be able to update the devices remotely without having to recall them.

C.2 Hardware

The final device design consisted of:

- a PIC18F46K20 microcontroller
- SST 25VF040 32 MiB flash memory
- Freescale MMA7341L $\pm 3G$ analogue accelerometer
- OSRAM SFH-3710 ambient light sensor
- ConnectBlue OBS411 Bluetooth module
- nine Avago HSMF-C114 RGB LEDs

The power subsystem consisted of:

- a generic Chinese-origin “033030” 250mAh lithium ion polymer (LiPo) battery
- a Texas Instruments TPS73033DBVR LDO 3.3V voltage regulator IC

- a Maxim MAX1555 battery charging IC

Input was to be by two C&K KMS231GLFS micro-miniature tactile switches. The battery and charging wiring harness would be connected via Molex PanelMate connectors.

I created circuit schematics for the required electrical subsystems using the `gschem` tool from the free software gEDA package. I used the `gnetlist` DRC2 module to perform schematic validation on the `gschem` schematic files. I then used the `gsch2pcb` script to forward-engineer the schematic files to an initial PCB layout and netlist for the gEDA `pcb` program.

In `pcb` I manually laid out component footprints and created the necessary vias and traces. As with the Activthings proof-of-concept prototype I decided to place the microcontroller (in a TQFP44 package) on the top of the board, along with the RGB LEDs and ambient light sensor. The Bluetooth module took up most of the space on the underside of the board along with the accelerometer, buttons, power subsystem ICs, and wire-to-board connectors.

PCB layout was especially challenging due to the need to avoid placing any vias under the Bluetooth module daughterboard (to avoid inadvertent shorts with the daughterboard's vias). Other concerns were keeping the Bluetooth module antenna clear of copper planes, and providing an adequate ground plane for signal traces. The vias needed to be very small (ten thousandths of an inch) but had to be a certain minimum size to avoid the need for costly laser drilling.

In laying out the LEDs on the PCB I moved the "individual", or middle, LED out of line with the ranking LEDs, so as to visually separate it from the others. I placed the ambient light sensor next to the individual LED.

The final PCB layout had four layers—top, bottom, signal/ground plane and signal/VCC plane. It was approximately 28×36mm in size. The board design was well outside of what I could construct myself and I therefore had to send it to a

Chinese board house to be professionally manufactured. In creating the first few evaluation devices I could, however, solder the components to the board by hand. The Bluetooth module and accelerometer had no exposed pads or leads, so I had to apply solder paste, place the components and then re-flow the solder using heat (in lieu of an infra-red oven I used a domestic electric frying pan). The other components could be placed under magnification using solder paste, precision tweezers, and a fine-tip soldering iron.

After proving the PCB and components worked as expected, I arranged for the Chinese board house to create 40 circuit boards and populate them with all the necessary components. This assembly process was carried out at the board house by automated pick-and-place robots.

C.3 Case Design

To create the plastic case, I used my personal 3D printer—a Makerbot Thing-o-Matic with Mk. 7 extruder, printing with 1.75mm ABS filament. I considered two main practical approaches to building the case—one would involve printing the case vertically (from the user's wrist upward), and the other would involve building the case horizontally (across the user's wrist). I chose the latter approach as it was the only practical way to create a case that curved to the contour of the user's wrist.

The casing would have to be made in two halves which would be joined to enclose the battery and electronics. Further, I would need some way of attaching the wristband, and some external contacts to allow power to be connected to recharge the battery. I came up with a simple solution to solve all three problems at once. I could print the two ABS case pieces with holes on each end of the correct dimension to accept stainless steel M3 screws. Each screw would enter a "screw pole" (a hollow cylinder), providing one attach point at each end of the case for a wristband. I would route a positive and negative charging wire from inside the case to a position under the head of each screw. When tightened the screws would pinch the wires, turning the screws themselves into external electrical contacts.

I inserted two cut-outs on one end of the housing to create button holes. I 3D-printed a thin pad with two buttons which would sit on top of the PCB switch actuators and protrude through the button holes in the casing. I also created three small clips inside the casing to hold the PCB in place, keeping the LEDs and buttons properly aligned inside the casing.

I had problems creating an individual cut-out for each LED—the resolution of my printer meant the small towers of plastic between the LEDs were brittle and were prone to stringing. To work around this, and to expose the ambient light sensor, I decided to create one large T-shaped cut-out. In practice this was achieved by creating one large gap in the bottom housing piece and a small gap (the base of the T) in the upper piece.

In the Activmon design I had used a combination of plastic and adhesive tape to create a light disperser, creating a soft glow from the RGB LED. I decided to take a similar approach with Activthings, creating a 3D-printed light disperser with a rectangular shape, flat top and holes in the base to direct the light from each LED. The disperser covered the ambient light sensor, but with a small enough thickness of plastic that adequate light could still reach it. After several design iterations I eventually settled on a disperser that self-aligned over the ambient light sensor, ensuring the light from the LEDs was directed into the correct holes.

I was then concerned that water, sweat, and other liquids would enter into the gap between the two case pieces and cause electrical shorting. As a solution I wrapped clear adhesive tape around the PCB and battery where they aligned with the join in the casing. I tested this solution by assembling an Activthings device, switching it on, and spraying it with water from the top, bottom, and sides. Only a small amount of water entered through the join and it collected on the adhesive tape, causing no shorting. I concluded the device would be adequately waterproof for normal use (rain, light water splashes, and sweat) not involving complete immersion or heavy

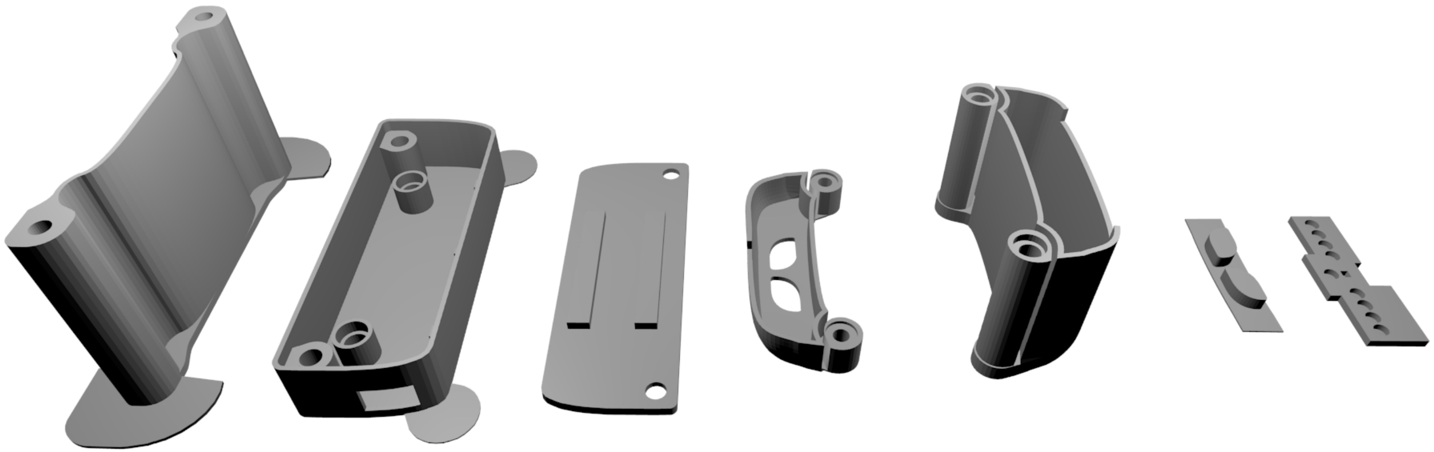


Figure C.1: 3D models used to print Activthings casing and charger parts. From left: Charging cradle platform, charging cradle PCB housing, charging cradle housing lid, Activthings case end-cap, Activthings main case, button pad, light disperser.

drenching.

I found that when I wore the fully assembled casing with the wrist strap, the edges of the casing pressed uncomfortably into my wrist. This was due to a property of the 3D printer—when printing the casing components it was necessary to ensure good adhesion with the printer's build platform, to avoid the piece moving during the build process (especially when forming the upper layers of a tall piece). This usually involved printing the bottom layers of the piece with the extruder nozzle close to the build platform, causing the first one or two layers to flare out. The result was a sharp edge at the bottom of the piece.

I tried to address this problem by deliberately shrinking the bottom layers in the 3D models of the casing components prior to printing. Unfortunately, when printing, the upper layers tended to cascade down on the smaller bottom layers, causing the same sharp edge. The solution was to manually smooth the edges of each casing piece by filing them with a bastard file. It was also necessary, for some casing parts, to lightly file either or both pieces to make them come together cleanly without a gap.

C.4 Charging and Power

Although I ultimately decided to use a charging cradle to recharge the device's internal battery, I did consider three possibilities: a charging cable, a cradle, or contactless charging. The previous Activmon prototype had used a charging cable. This is where the device has a socket into which the user plugs a cable to charge the battery. Cradle charging involves providing a cradle into which the device to be charged sits. When the device is aligned correctly with the cradle, a set of contacts on the device make an electrical connection with contacts on the cradle to create one or more circuits.

With a cable-based approach, it is too easy to lose the end of the cable in a tangle of other cables or to have it drop on the floor. When the cable is located, depending on the connector type, it can be frustrating to work out which way to orient the connector so that it will mate correctly with the socket. I anticipated such a charging process would make it difficult for participants in a long study to develop a charging routine, causing a higher drop-out rate as charging became too inconvenient.

Contactless charging was my preferred option, as it is the simplest of the three. This is where energy is transmitted from the charger to the device using electromagnetic induction, i.e. wirelessly, without the need for a direct electrical connection. The charger usually takes the form of a flat mat onto which the device to be charged can be placed in any orientation. The mat uses electricity to create a strong varying electromagnetic field which is picked up by the device and turned back into electrical energy for charging.

Unfortunately, at the time I explored this option, it was not possible to buy an off-the-shelf contactless charging system—that is, a complete solution consisting of the necessary integrated circuits and inductors. Although the system is theoretically simple, there are a number of engineering challenges to implementing it in a safe, efficient, and effective way. I concluded that I had neither the time or expertise to implement my own contactless charging system.

I considered the next best option was to provide a charging cradle. Given the limitations of battery power and size, it was probable that the new Activthings device would need to be charged once a day like Activmon. If I were to force users into a pattern of habitual recharging, it was important to make the charging process as simple and stress-free as possible. A cradle, as opposed to a cable that must be plugged into the device, can be put it in one place where it will be easy to find. Charging the device is simply a matter of dropping it into the cradle, and if the interface is well designed then the orientation of the device to the cradle is more obvious.

I designed the charging cradle as three separate components, which I 3D printed.

The "platform" component consisted of a flat table on which the Activthings device would sit. The "charger housing" component was a box-like structure that would attach sideways to the platform. The "charger lid" snapped onto the charger housing, and all three were joined together with two M3 screws.

I configured the charger housing to accept a simple circuit board, onto which was mounted a mini USB socket and two gold spring-loaded pins. When the circuit board is installed into the charger housing, the spring-loaded pins protrude out over the edge of the charging platform. The Activthings device is connected to the dock by angling it toward the spring pins, such that they make contact with the screws on the device. The device may then be pushed down until it is flat against the charging platform, with a small lip on the platform retaining it against the spring pins.

I created a cut-out in the charger housing to expose the mini USB connector on the charger PCB. The PCB simply electrically connects the `GND` and `VBUS` pins of the mini USB connector to the spring pins, providing charging power to the docked Activthings device. The connector can accept either a USB mini A or B connector, usually part of a USB A-to-mini B cable, that is connected at the far end to a computer or USB charger.

Unlike the Activmon device, with its hardware power switch, Activthings' power states are controlled in software. Even when the device is "off" the microcontroller wakes up on a timer every few seconds to sample the state of the buttons. If no buttons are pressed the microcontroller goes back into sleep mode (consuming minimal power). If a button press is detected, and the button being held is the "power" button, the microcontroller wakes and monitors the button state for three seconds. If the button is still held in after that time the device switches into "on" mode. This is the same approach used on most modern battery-powered electronic devices, e.g. mobile phones, tablets, remote controls, toys, and games.

When Activthings is running, an interrupt service routine checks the state of the buttons once a second. If the "power" button is pressed for three consecutive interrupts (three seconds or more) the device immediately switches to "off" mode. This involves shutting down power-draining peripherals (the Bluetooth radio and accelerometer) and sending the microcontroller into a low-power sleep mode (as above). Either button on Activthings can act as the "power" button—this is defined in software. In practice I chose the top button—the one in the top-right-hand corner of the device—as the power button. The bottom button—the one in the bottom-right-hand corner—allows the device to be paired to a different mobile phone (this is discussed below).

When Activthings is placed into the charging cradle, the MAX1555 charging IC immediately begins charging the battery. The 5V external power line is also connected to one of the microcontroller's digital input pins via a voltage divider, which reduces the voltage to the microcontroller's operating voltage of 3.3V. A rising edge on this pin triggers an interrupt in which the microcontroller reboots into a "charge monitoring" mode.

The MAX1555 IC presents an open-drain charge status pin, which is low when charging is in progress and high-Z otherwise. This pin is pulled up to 3.3V with an external resistor and connected to the microcontroller, allowing the microcontroller to determine whether the battery is charging or if charging has stopped (i.e. the battery is close to full charge). The microcontroller turns the middle RGB LED to red if charging is under way and then to green when charging completes. This provides the user with a visual indicator, allowing them to confirm that charging is happening and know when it has completed.

The positive terminal of the battery is connected to an analogue input on the microcontroller via another voltage divider. This divider scales the nominal range of voltages across the battery (approx. 3.5–4.2V) into a range acceptable to the microcontroller (a maximum of 3.3V). The microcontroller's analogue-to-digital converter (ADC) is then used to generate an internal eight-bit representation of the battery voltage. The microcontroller monitors this voltage using a periodically triggered interrupt and switches the device off if the battery voltage is deemed too low for normal operation (currently <3.5V).

All of this power information (external power connected, charge status, and battery voltage) is logged in the microcontroller's flash memory. In normal operation the battery voltage is logged every 15 minutes. In charge monitoring mode all external power connect/disconnect events are logged, as well as all charge start/stop events. Battery voltage logs allow monitoring of battery drain rate and performance, and can be used to construct a discharge curve for the battery under various operating conditions. Similarly, charging statistics allow the recharge performance of the battery to be monitored. These data also allow for monitoring of user behaviour, e.g. how often the device is recharged, when, and for how long.

C.5 Bluetooth Interface

The ConnectBlue OBS411 Bluetooth Radio is connected to the microcontroller's EUSART `RX` and `TX` lines, with hardware flow control lines `CTS` and `RTS` connected to two microcontroller IO pins. The microcontroller communicates with the Bluetooth module using AT commands, similar to the interface to a Hayes (or other generic) Smartmodem. For example, it can use generic commands such as `ATE0` to disable modem character echo, and Bluetooth stack specific commands such as `AT*AGI` to initiate an enquiry, or `AT*ARSS` to perform a service search using the Bluetooth service discovery protocol (SDP).

When Activthings starts up it requests the list of paired devices from the Bluetooth module. Initially the module is not paired with any device and so this list is empty. Activthings indicates this by displaying two blue lights—one at each of the far ends of the face of the device. Activthings then enters "pairing mode". In this mode it instructs the Bluetooth module to perform an enquiry scan to locate any discoverable Bluetooth devices within range. At this point the user should enable discoverability on their mobile phone.

Activthings then instructs the Bluetooth module to attempt to create a pairing with each device found (the expectation is that this will only be one device—the user's phone). At this point the user should see a notification on their phone that the Activthings device wishes to pair. If the user accepts this notification a pairing is created. Because the Activthings device has no numerical display or PIN entry system the pairing is performed in "just works" mode without a PIN code. There is the potential for a man-in-the-middle attack during the pairing process. However, I consider this to be unlikely, and in any case inconsequential given the nature of the data being transmitted.

Activthings subsequently instructs the Bluetooth module to perform a service discovery (SDP query) on the paired device. Activthings first looks for a service providing the PAN profile, then DUN, then SPP, preferring whichever it can find first in this order. During this time two yellow lights are shown. If a suitable service is found, Activthings shows two green lights to indicate this. Using Activthings' bottom button the user can later remove this pairing and connect Activthings to a different phone if needed (for example if the user loses or breaks their phone or if they buy a new one).

Activthings then attempts to create either a PAN connection (for PAN profile devices), or a PPP connection (for DUN/SPP profile devices), over which it can send IP packets with UDP payloads to the server. For PAN connectivity I created minimal implementations of the IP, UDP, ARP and DHCP protocols. PPP connectivity additionally required implementations of LCP and IPCP.

C.6 Client-Server Protocol

The Activthings device (the client) can send one of three main packet types: a "bins" packet to send activity data to the server, a "params" packet to request data from the server, or a “firmware” packet to request new firmware. Each client packet contains a packet type, the unique Bluetooth MAC address of the device, the device’s current firmware version, and a sequence number. In addition, bins packets contain activity rate data. Every packet is appended with a 16 bit CRC.

When the server receives and successfully processes a client packet, it will send a response packet back to the client. At a minimum this response packet consists of a field containing the sequence number sent by the client (to ACK the client’s packet) or `0xFFFF` (to NAK the client’s packet). Params replies contain additional data generated by the server in relation to the user’s activity. Every reply is appended with a 16 bit CRC.

Firmware request and response packets are a special case—the sequence number field is used to request a particular firmware block which is then returned by the server. If a firmware update is needed (the server offers a higher firmware version than the client is currently using), the client requests all firmware blocks in order, caches them in flash memory and then re-programs itself once all blocks are received.

In a params reply the server can request the client enter one of a number of modes. For the “static”, “group” and “combined” modes, the server params packet specifies five colours as five RGB triplets, along with an offset to control the positioning of the colours on the device. If the offset is zero the five colours will be displayed on the top five LEDs on the device. If the offset is one the first LED will be blank and the following five will be lit. In “group” and “combined” modes, all users will receive the same five ranking lights but each will receive a different offset—this offset depending on their ranking within the group.

For example, assume a group of five users—A, B, C, D, and E—have the colour codes blue, cyan, yellow, magenta, and white and that, ranked against one another, they happen to be alphabetically ordered. All users will receive the five colours blue, cyan, yellow, magenta, and white from the server, in that order. However user A, being ranked first, will receive an offset of 4, turning the lights below her middle light cyan, yellow, magenta and white, thus indicating she is beating those other users. User E, being ranked last, will receive an offset of 0, turning the lights above his middle light blue, cyan, yellow and magenta, thus indicating the other users are doing better than him.

C.7 Activthings Schematics

The following are schematic diagrams for the Activthings device, as created in the gschem program. The schematic is split across five linked diagrams.

The first and second schematics (Figures C.2 and C.3) describe the input/output (IO) subsystem of Activthings. `U6` in schematic one is a ConnectBlue OBS411 Bluetooth module. The module is a daughterboard that is mounted via its `J6` pads to the Activthings main PCB. This module is connected to the microcontroller (`U1`) and permits it to connect to the user's mobile phone to upload and download data from the Activthings server.

The Bluetooth module communicates to the microcontroller using a serial link, with `U6` pin 13 (`UART_RXD`) being connected to `U1` pin 44 (`TX`) and `U6` pin 11 (`UART_TXD`) being connected to `U1` pin 1 (`RX`). Hardware flow control is implemented using an RTS/CTS system, with `U6` pin 12 ($\overline{\texttt{UART\_RTS}}$) being connected to `U1` pin 8 (`RB0`) and `U6` pin 10 ($\overline{\texttt{UART\_CTS}}$) being connected to `U1` pin 9.

The serial link has a baud rate of 57,600 bps, 8 data bits, 1 stop bit, and no parity (`8N1`). It is possible to operate the link at higher speeds, but this places greater demand on the PIC (to read and buffer incoming bytes) and is unnecessary given the nature of the data being exchanged. The PIC's EUSART handles serial I/O on pins 1 and 44 (`RX` and `TX`) with RTS/CTS flow control pins being general-purpose IO pins which are given a flow control function by the PIC's firmware.

To allow the Bluetooth module to be switched on and off, to conserve power, the `GND` pin (`U6` pin 25) is connected through a bipolar NPN transistor, `Q2`, controlled by the

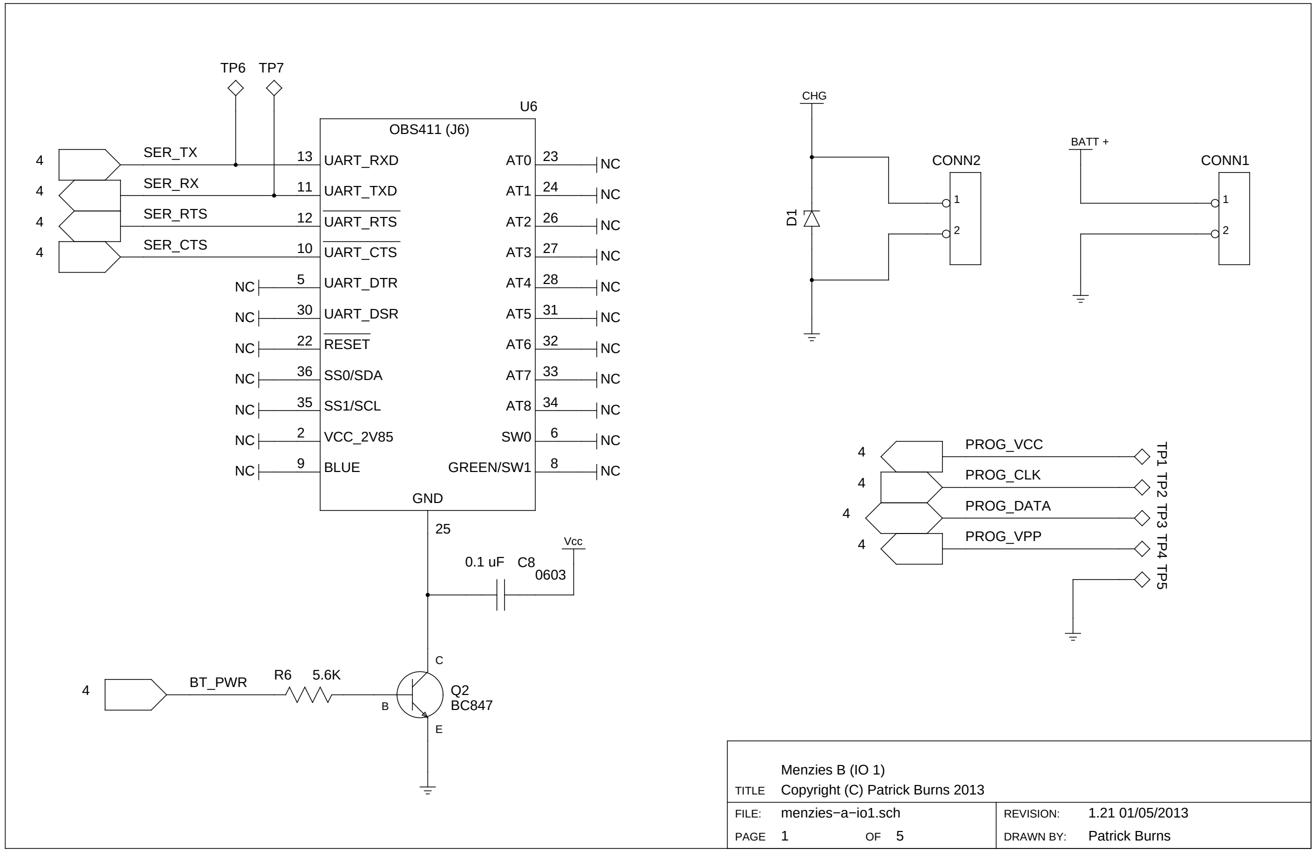


Figure C.2: Schematic 1: Bluetooth, battery, charging and programming I/O

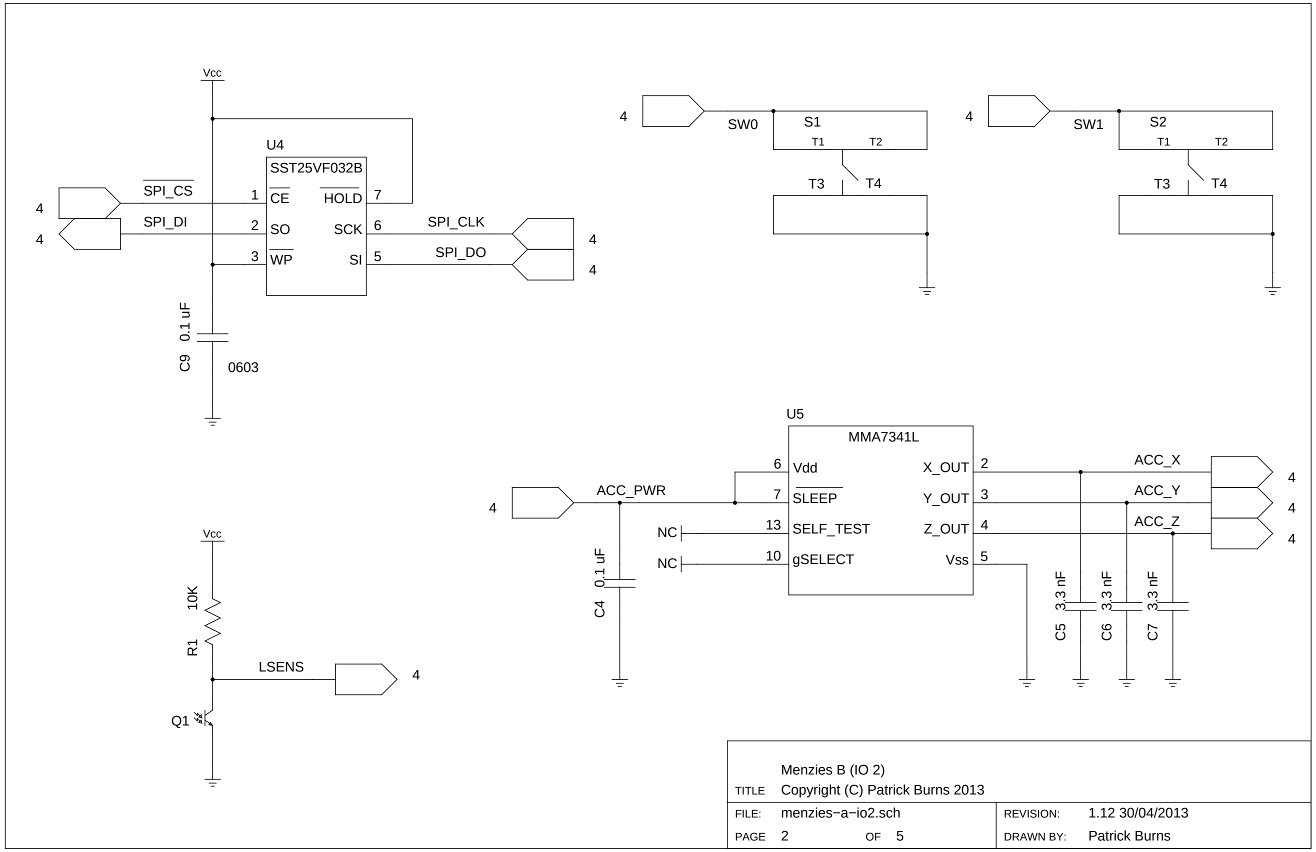


Figure C.3: Schematic 2: Light sensor, switches, flash memory and accelerometer I/O

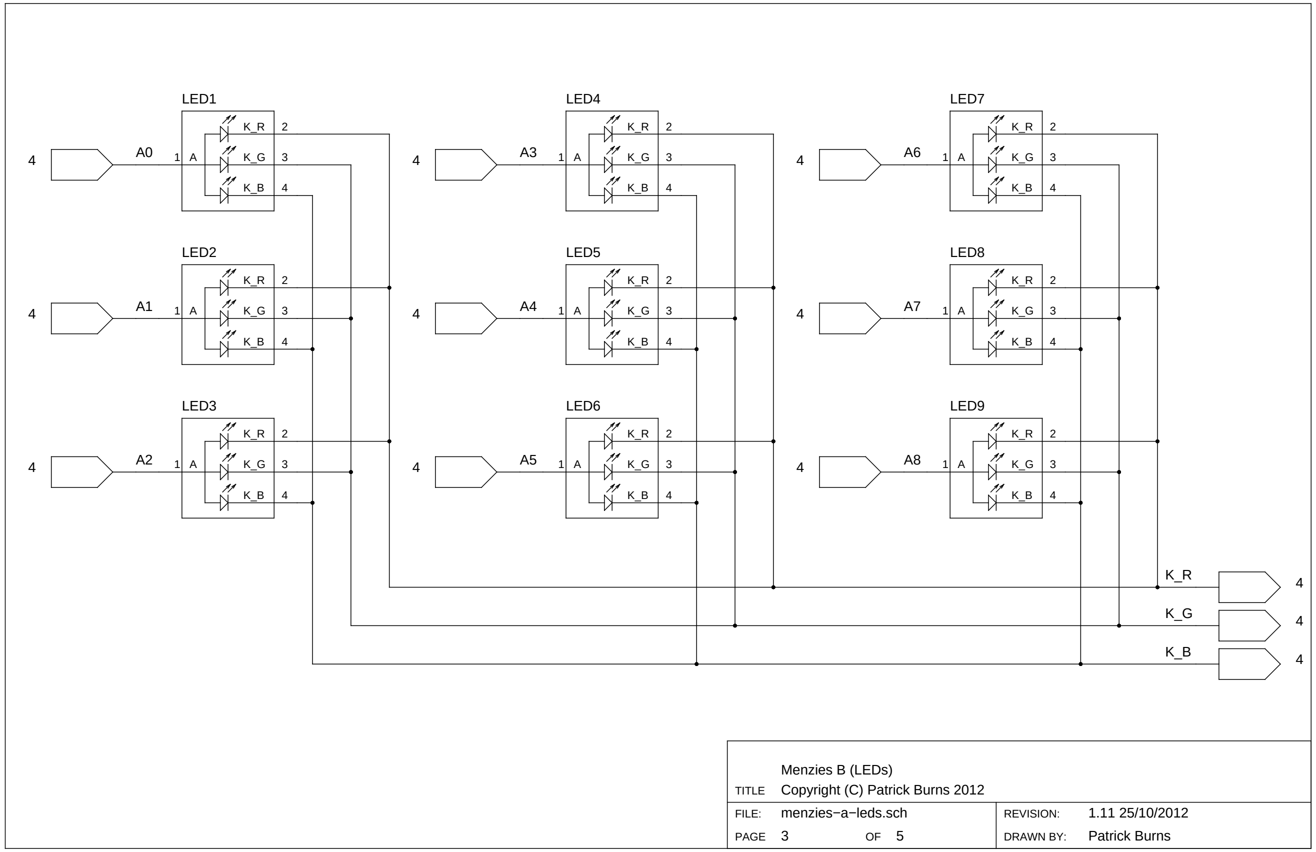


Figure C.4: Schematic 3: LEDs

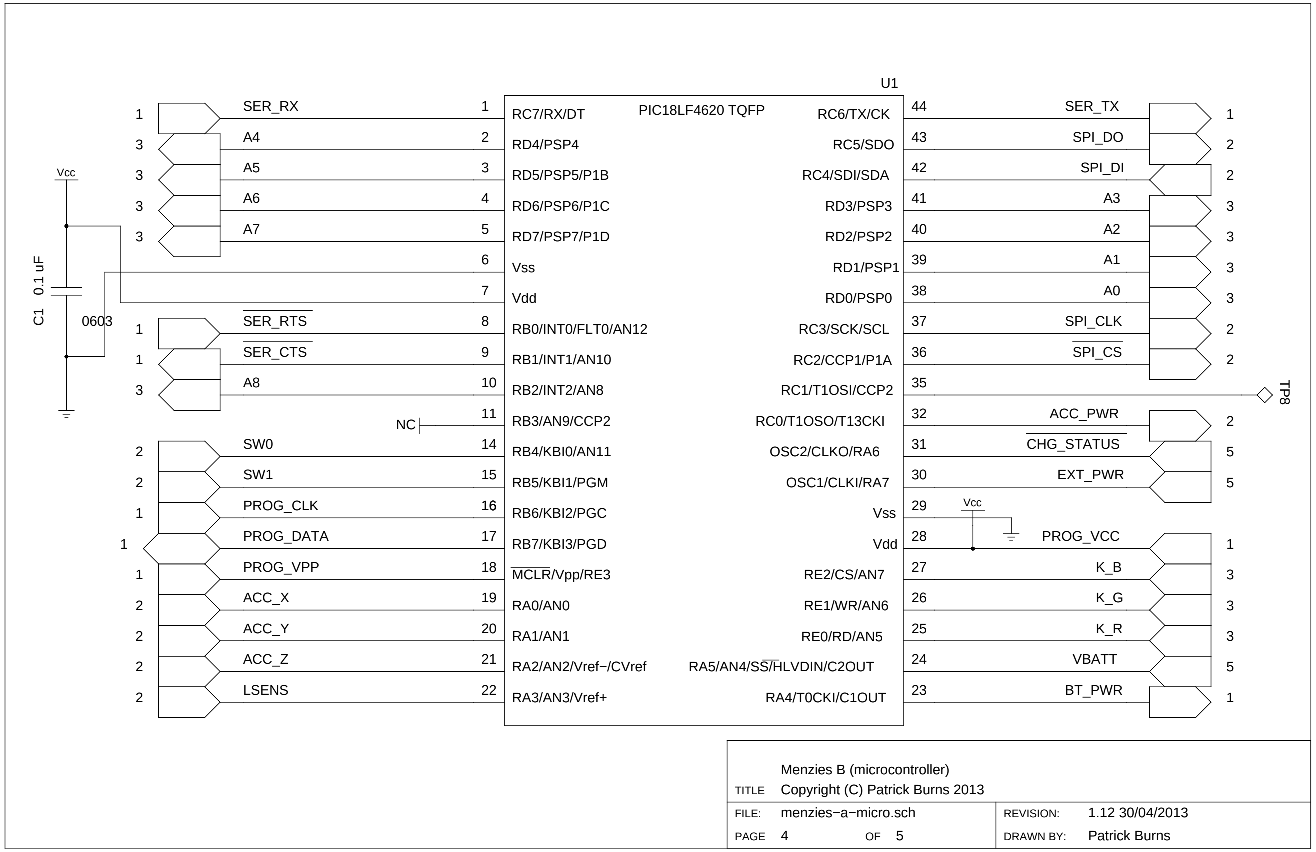


Figure C.5: Schematic 4: Microcontroller

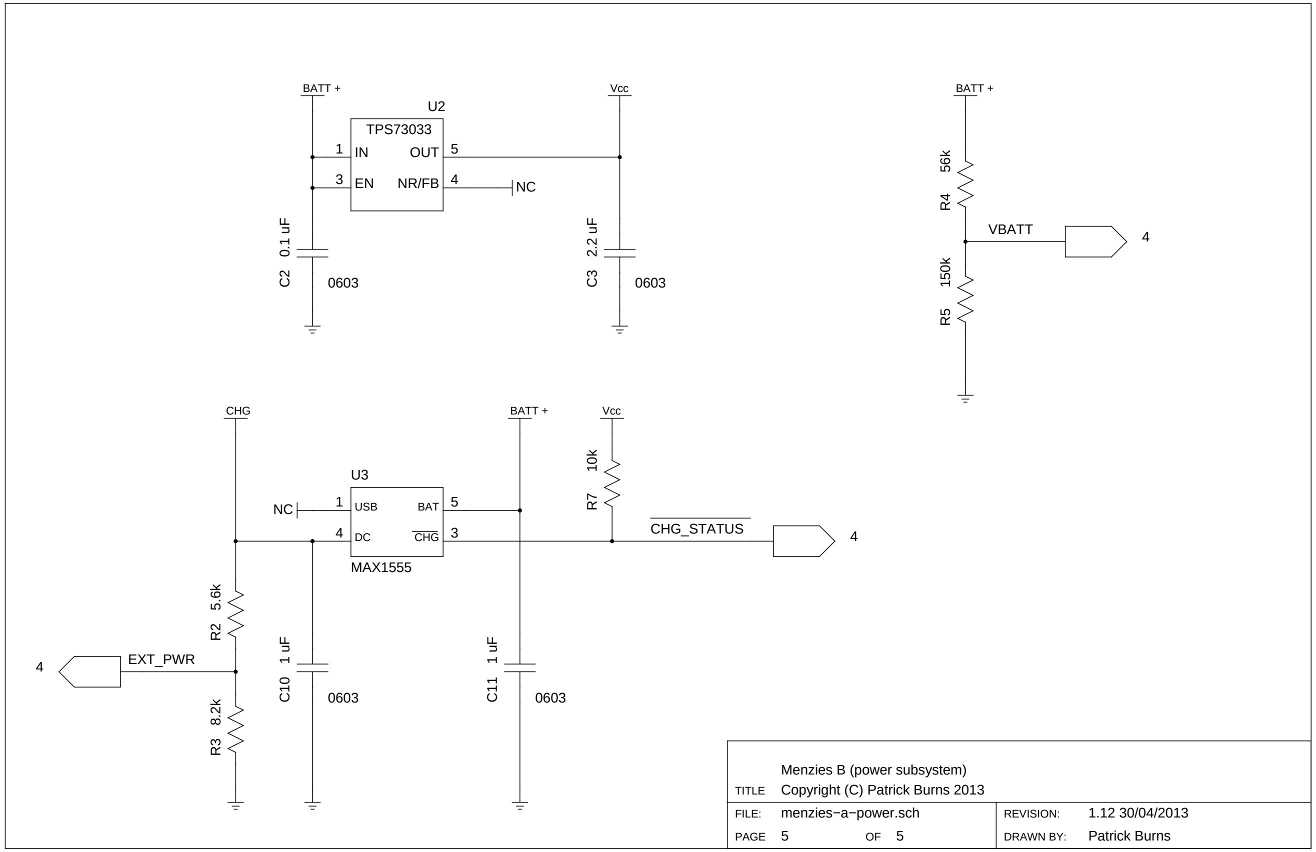


Figure C.6: Schematic 5: Power subsystem microcontroller (U1) pin 23. R6 is a current limiting resistor. The microcontroller drives pin 23 high to switch on power to the Bluetooth module, U6, and drives it low to disable power. It is also necessary for the microcontroller to switch the TX and CTS pins to a high-Z state whilst U6 is powered down to avoid power waste through unintended parasitics. Note that the microcontroller should keep RX and RTS at a high-Z state regardless of the power state of U6 (as they are inputs to the microcontroller). C8 is a decoupling capacitor.

CONN1 is a two pin Molex PanelMate connector to which battery power is supplied by a LiPo battery, with a nominal voltage of 3.7 V (typically varying from 4.2 V to 3.5 V depending on battery discharge state). CONN2 is also a two pin Molex PanelMate connector and is for connection of external power for battery charging (via the Activthings charging cradle). The pins are connected to a transient voltage suppression (TVS) diode to dissipate any static discharge that may occur by the user touching the external charging connector or having it rub against the user's clothing.

Test points TP1–TP5 are for in-circuit serial programming (ICSP) of the PIC microcontroller, U1. They allow an appropriate programmer (such as the PICkit2) to be connected to the microcontroller for download of programming. Ordinarily ICSP would only be used in the initial testing and construction of each device—a boot loader allows new firmware to be delivered over the Internet, via Bluetooth module U6, thereafter.

In schematic two (Figure C.3), U4 is a flash memory IC. It is connected to the microcontroller, U1, via a SPI serial connection. U4 pin 5 (SI) is connected to U1 pin 43 (SDO) and U4 pin 2 (SO) is connected to U1 pin 42 to allow bidirectional serial communication. The microcontroller generates a clock on its pin 37 (SCL) which is connected to U4 pin 6 (SCK). Microcontroller GPIO pin 36 (RC) is connected to U4 pin 1 ($\overline{\texttt{CE}}$) to act as a chip enable. The microcontroller drives this pin low to send and receive data to/from the flash memory IC and drives it high to indicate the end of communications. The `SDO`, `SDI`, and `SCK` pins of `U1` are driven by the microcontroller's SPI peripheral. `C9` is a decoupling capacitor.

The collector of the phototransistor, `Q1`, is connected to the microcontroller's GPIO pin 22 (`AN3`). The collector is pulled high by 10K resistor `R1`. As the phototransistor is exposed to photons it begins to conduct between its collector and emitter, bringing the collector junction closer to `GND`. Thus the microcontroller, `U1`, sees a signal close to `GND` when there is significant ambient light, and a signal close to `VCC` when there is little ambient light. `U1` pin 22 is multiplexed with the microcontroller's ADC, allowing the analogue light-dependant voltage to be converted into a digital representation.

`U5` is a three-axis accelerometer. Pins 6 and 7 (`VDD` and $\overline{\texttt{SLEEP}}$) are connected to microcontroller, `U1`, pin 32 (`RC0`) to allow the microcontroller to disable power to the accelerometer when it is not needed. The microcontroller drives pin 32 high to provide power to the accelerometer and disable its sleep mode. (The accelerometer uses very little power and therefore can be driven entirely from current sourced by the microcontroller's GPIO). `SELF_TEST` and `gSELECT` (pins 13 and 10) are left floating—they are internally pulled low by the accelerometer. In the case of `gSELECT` a low state selects $\pm 3G$ sensitivity. Pins 2, 3 and 4 (`X_OUT`, `Y_OUT` and `Z_OUT`) are analogue signals representing acceleration in the x, y, and z axes respectively. Capacitors `C5`, `C6` and `C7` are for noise suppression, as per Freescale recommendations. `C4` is a decoupling capacitor.

Switches `S0` and `S1` are connected to `GND` (on two poles of each switch) and to microcontroller pins 14 (`RB4`) and 15 (`RB5`) (on the other two poles). When a switch is depressed it will present a ground potential to the microcontroller pin to which it is connected. `RB4` and `RB5` are pulled high by weak internal pull-ups within the microcontroller, avoiding a floating potential when the switches are not depressed.

Schematic 3 (Figure C.4) shows the circuits for powering Activthings' nine red-green-blue light-emitting diodes (RGB LEDs). The LEDs are of a common-anode configuration. Each of the anodes is connected to a separate GPIO pin on microcontroller `U1`. These are `RD0`–`RD7` on the microcontroller IO port `D`, and the third bit of IO port `B`, `RB2`. The red, green and blue cathodes are each interconnected to a red, green or blue bus. These red, green and blue buses are connected to pins 25 (`RE0`), 26 (`RE1`) and 27 (`RE2`) on the microcontroller, `U1`, respectively. The microcontroller uses a matrix scanning algorithm to control each LED (and each colour channel of each LED) individually.

Schematic 5 (Figure C.6) shows Activthings' power subsystem. IC `U2` is a fixed-voltage (3.3V) low drop-out regulator. The positive terminal of the battery is connected to pins 1 and 3 (`IN` and `EN`) to enable the regulator. 3.3V is output on pin 5 (`OUT`) which is connected to the `VCC` net. Capacitors `C2` and `C3` are required to stabilise the regulator and provide noise suppression and transient smoothing. There is no need for any connection to the noise reduction pin 4 (`NR/FB`), as additional smoothing of the regulated output is not required for this application.

IC `U3` is a Maxim MAX1555 lithium ion battery charging IC. Pin 5 (`BAT`) is connected to the positive terminal of the battery to allow it to be charged. Charging power is supplied via pin 4 (`DC`), which is connected to charging connector `CONN2`. Note that the MAX1555 can be powered by either pin 1 or pin 4 (`USB` or `DC`) depending on the available power source. When the `USB` pin is connected, the charging IC draws no more than one USB "unit load" (100mA) in order to comply with requirements in the USB standard that a device that is not able to negotiate power needs must draw no more than this amount. Although Activthings' charging cradle uses USB connectors and a USB cable, it is not intended to connect to a real USB host (rather a USB wall charger) and therefore this requirement is not relevant. By using the `DC` pin the MAX1555 will draw significantly more power and therefore charge the battery faster, yet still remain well within the power envelope of the USB charger.

U3 pin 3 ($\overline{\texttt{CHG}}$) provides an output that is open-drain when charge current is over a certain threshold (charging is under way) and high-Z when charging current decreases (charging is mostly complete). This pin is pulled high by resistor `R7` and connected to the microcontroller's pin 31 (`A6`). When charging is under way the MAX1555 will pull the pin to ground potential, and when charging is finished the pull-up resistor will draw the pin to `VCC`. The microcontroller can thus detect when the battery is being charged.

The `DC` pin (pin 4) is also connected to microcontroller pin 30 (`RA7`) through the voltage divider consisting of resistors `R2` and `R3`. When 5V external power is connected the voltage divider generates an approx. 3.3 V potential at this pin, providing a logic high to the microcontroller. When external power is disconnected the pin is drawn to ground through `R3`, creating a logic low. Thus the microcontroller is able to detect when external power is connected.

Capacitors `C10` and `C11` are stabilisation and smoothing capacitors, as per Maxim recommendations.

The combination of the voltage divider of `R2` and `R3`, and the $\overline{\texttt{CHG}}$ pin of `U3`, pin 3, allows the microcontroller to detect when external power is connected separately from detecting battery charging. Thus the microcontroller can show some indication when the device is in the charging cradle as well as showing a charge state indication. The external power sensing function can also be used to wake the microcontroller from sleep in order to display a charging status indication.

Resistors `R4` and `R5` form a voltage divider to reduce the battery positive terminal voltage to something within a range acceptable to the microcontroller (0–3.3 V). The centre of the divider is connected to microcontroller pin 24 (`AN4`). This pin is multiplexed with the microcontroller's analogue to digital converter, allowing the microcontroller to convert the battery voltage into a digital representation.

The microcontroller is then able to estimate the state of charge of the battery based on its voltage. The power regulator `U2` will provide the microcontroller with 3.3 V regardless of the battery voltage (as long as it is at least a few hundred mV above 3.3 V) essentially providing the microcontroller with a fixed reference against which to measure the battery voltage. Note that this is an estimate only as the microcontroller is reading voltage under load, not open-circuit voltage.

Schematic 4 (Figure C.5) shows microcontroller U1 and all connections to the peripheral devices previously discussed. Pin 35 (`RC1`) is connected to test point `TP8` to permit future expansion or debugging. Capacitor `C1` is a decoupling capacitor.

C.8 Activthings PCB Layout

The following are Activthings PCB layout files, as created in the open-source `pcb` program. Please note they have been enlarged for readability and are not to scale.

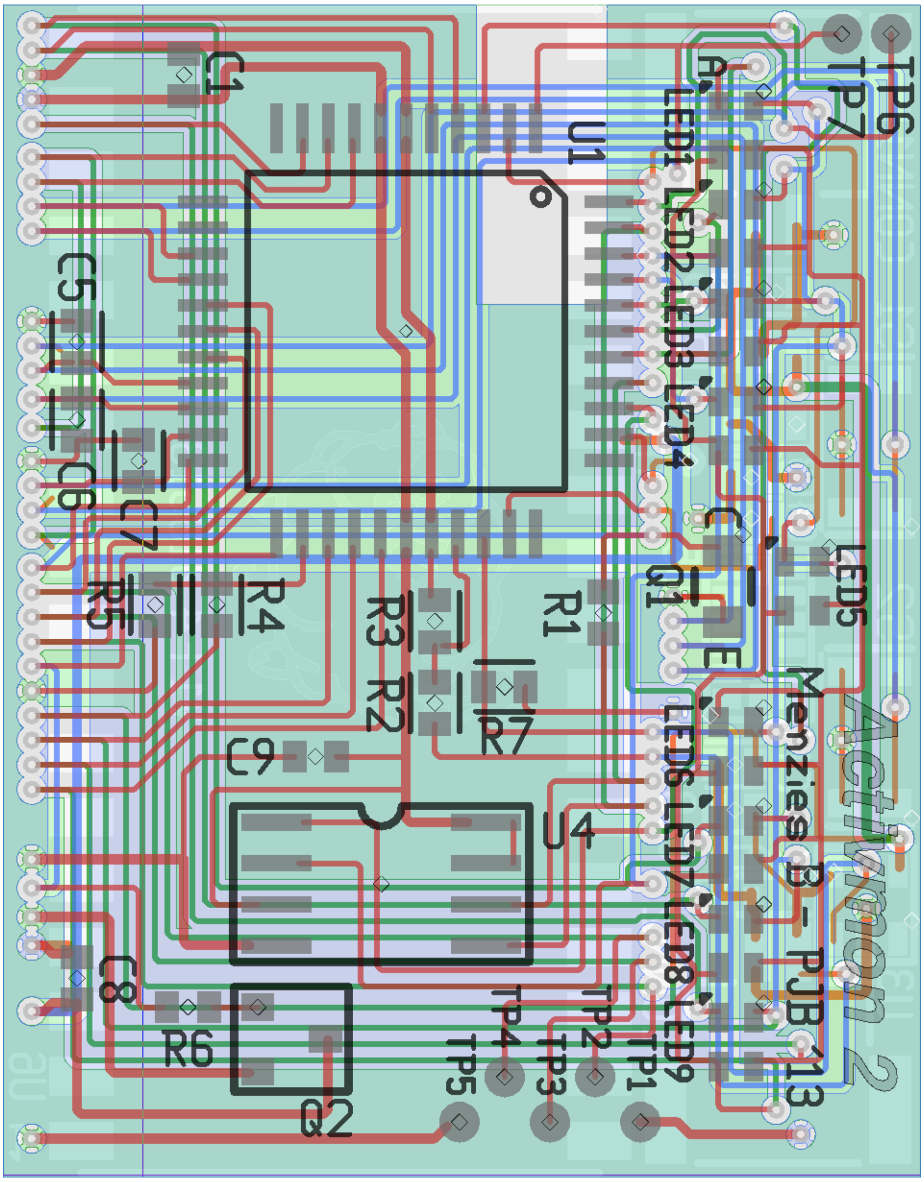


Figure C.7: Composite view of all PCB layers

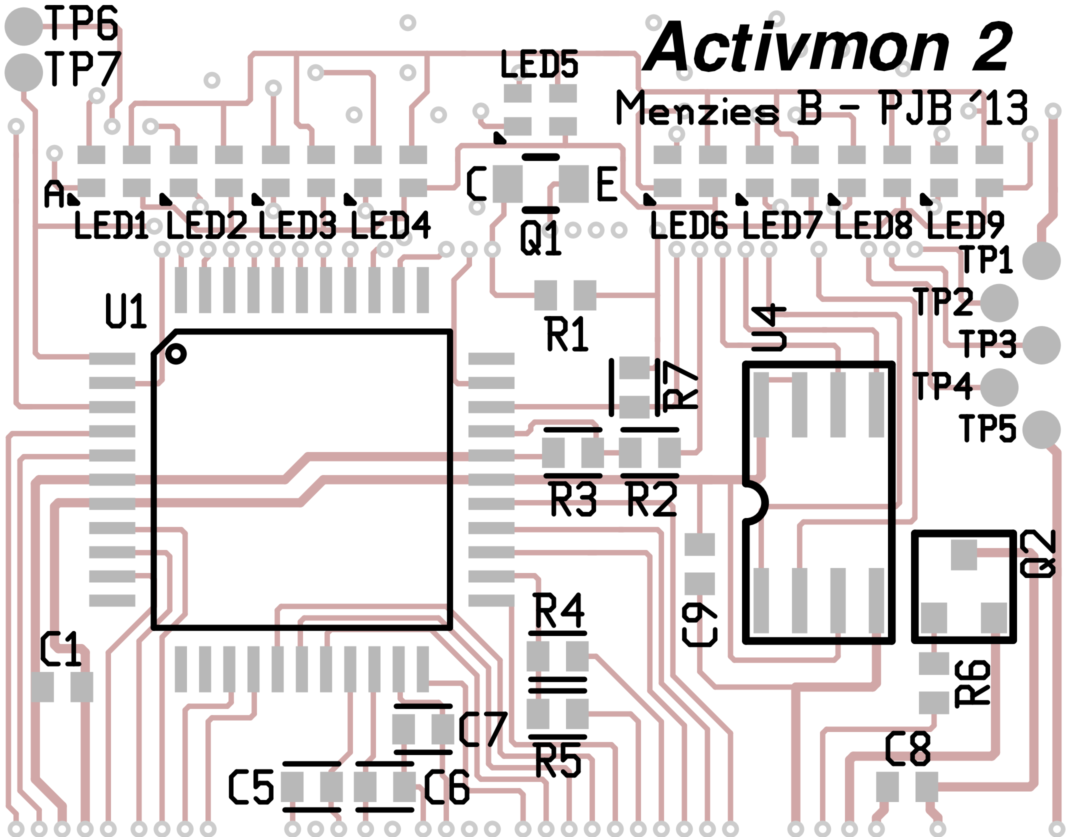


Figure C.8: Top layer assembly drawing

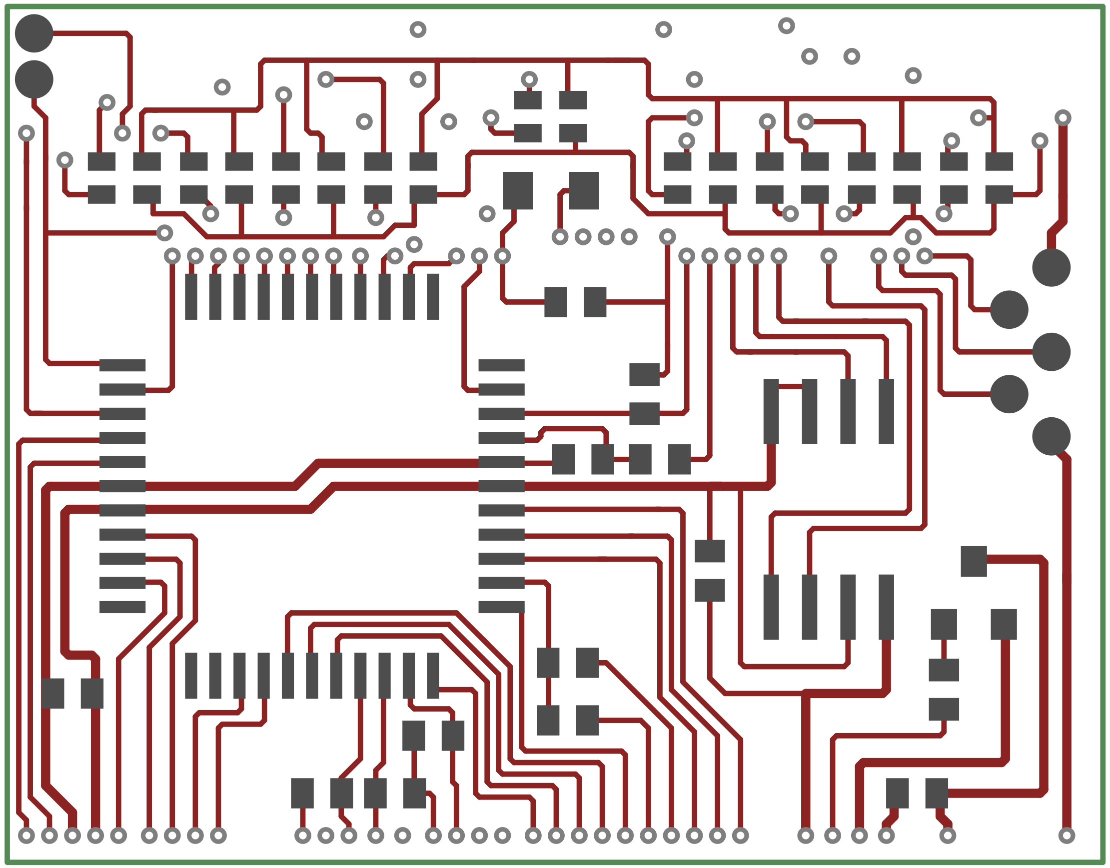


Figure C.9: Top layer

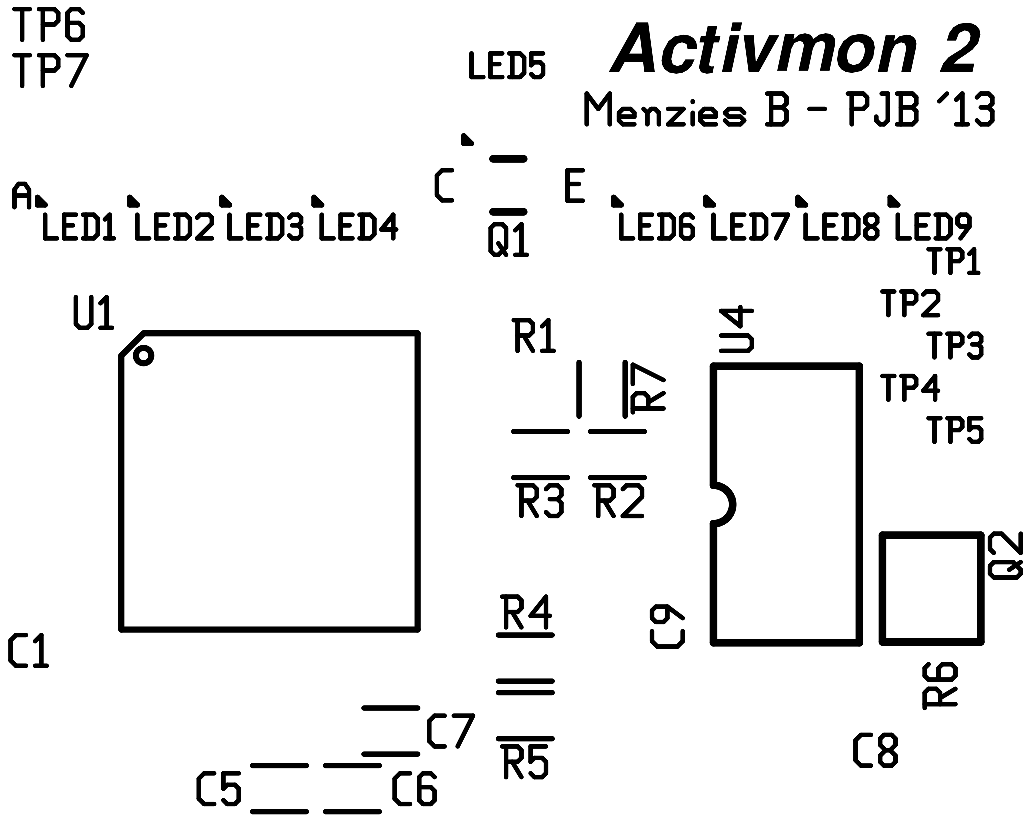


Figure C.10: Top layer silk screen

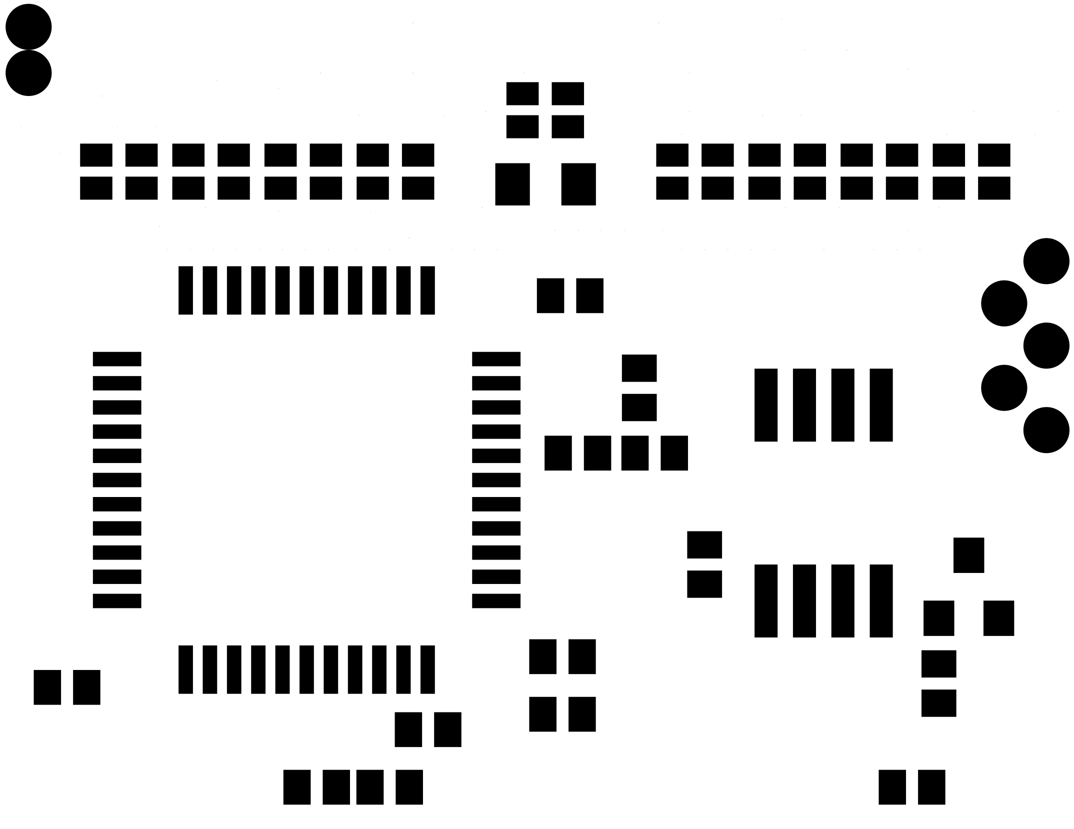


Figure C.11: Top layer solder mask

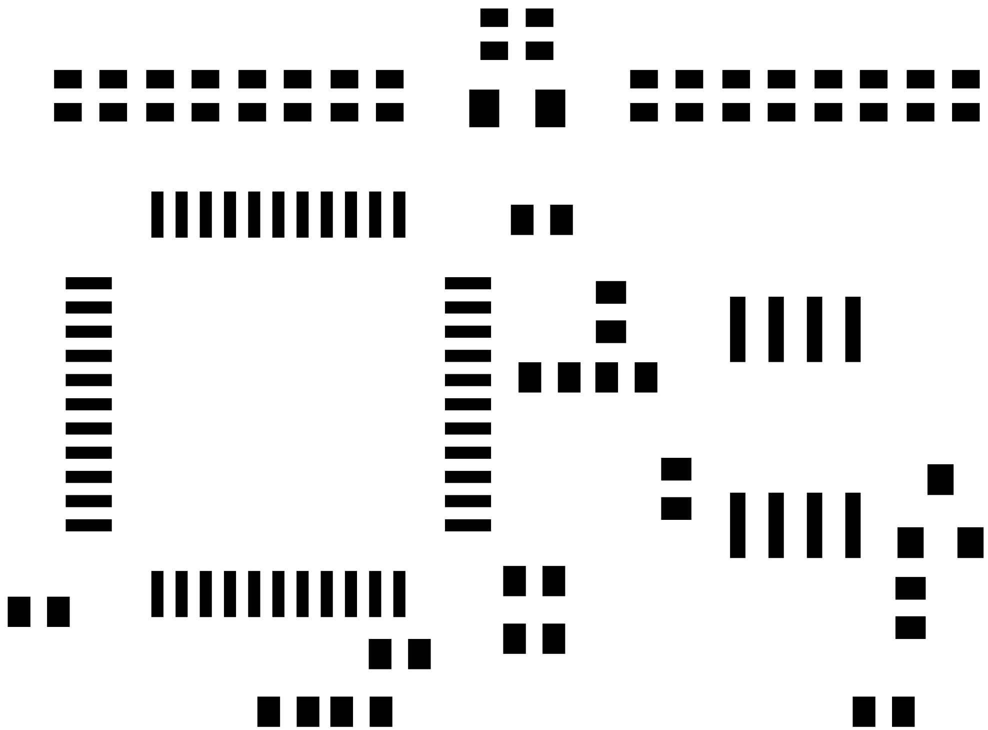


Figure C.12: Top layer solder paste mask

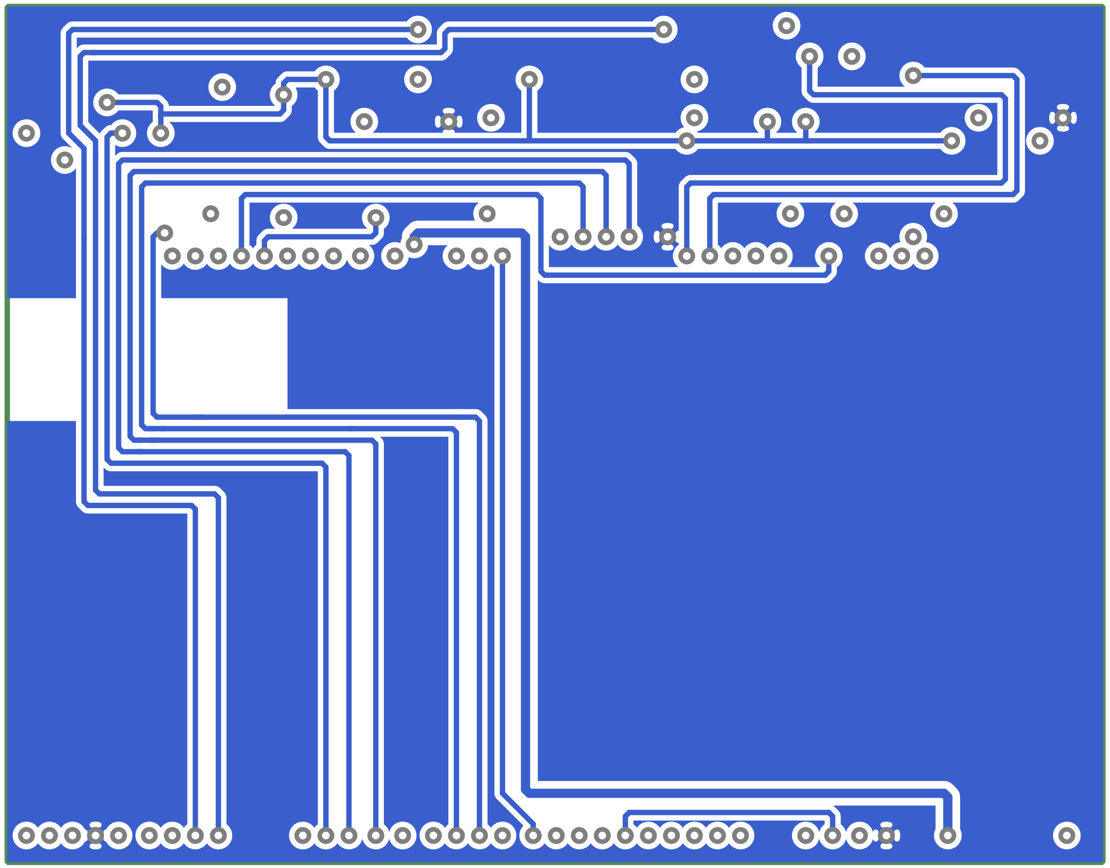


Figure C.13: Internal layer 1

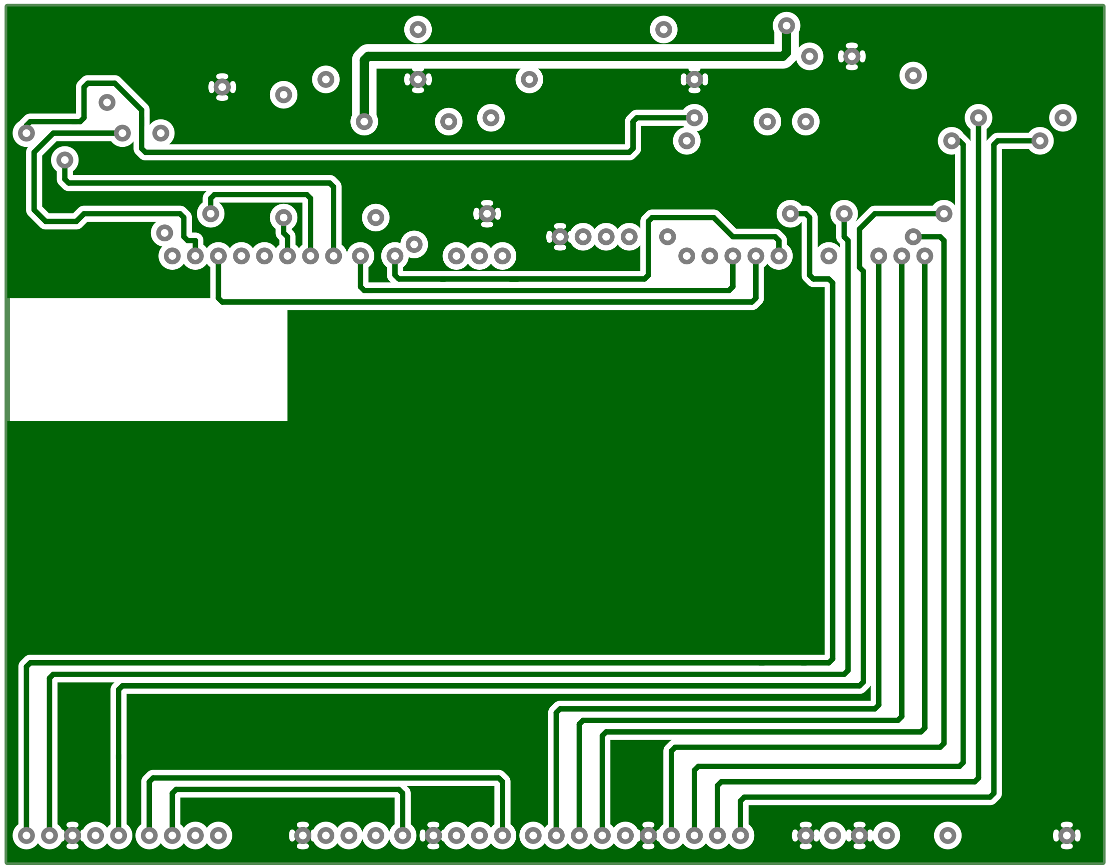


Figure C.14: Internal layer 2

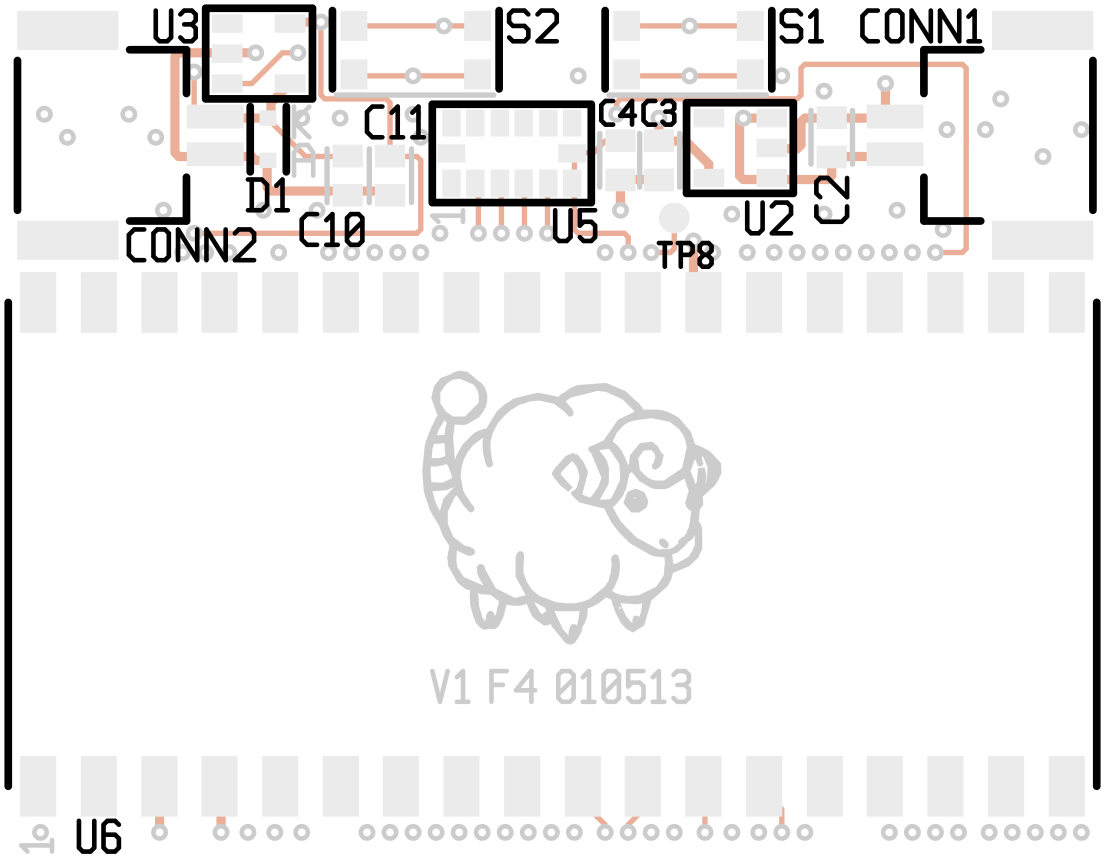


Figure C.15: Bottom layer assembly drawing

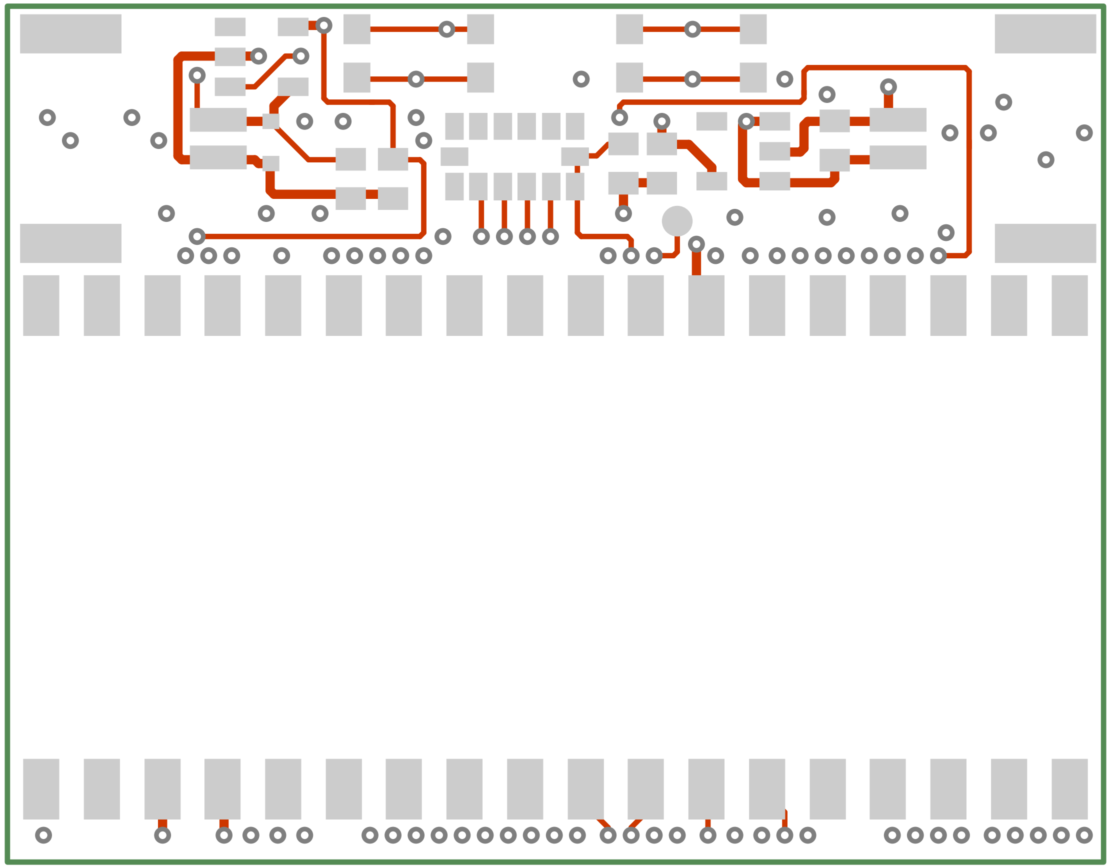


Figure C.16: Bottom layer

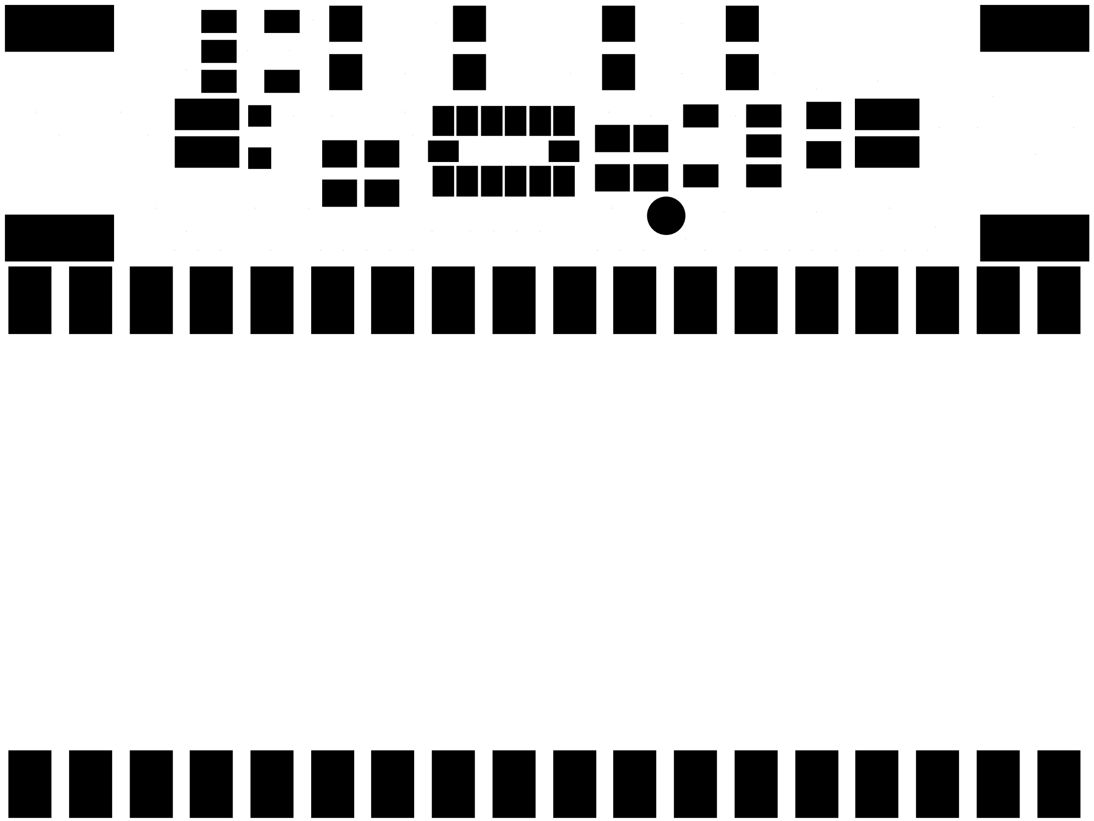


Figure C.17: Bottom layer solder mask

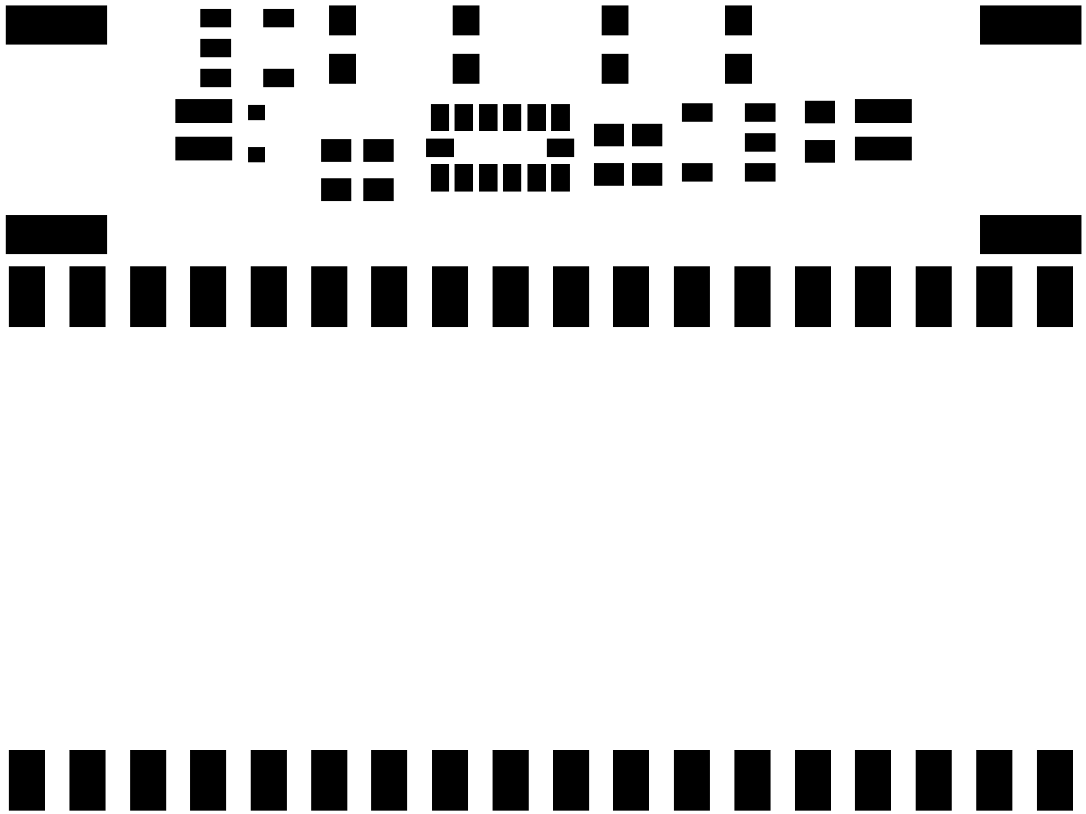


Figure C.18: Bottom layer solder paste mask

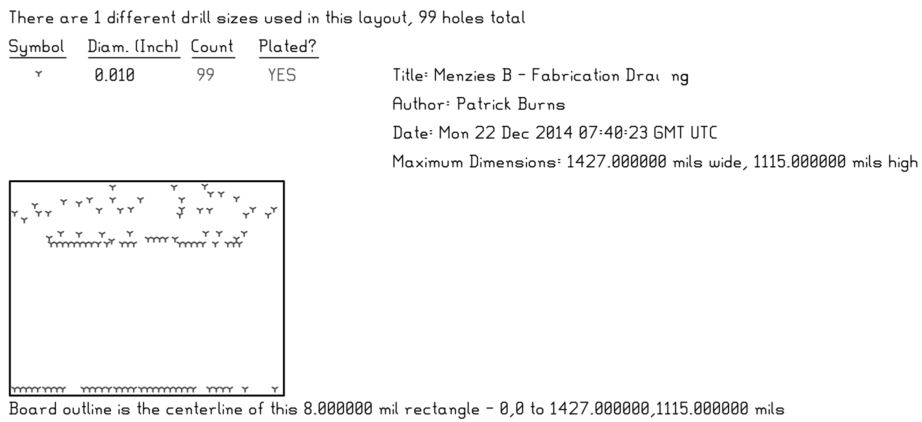


Figure C.19: Fabrication diagram

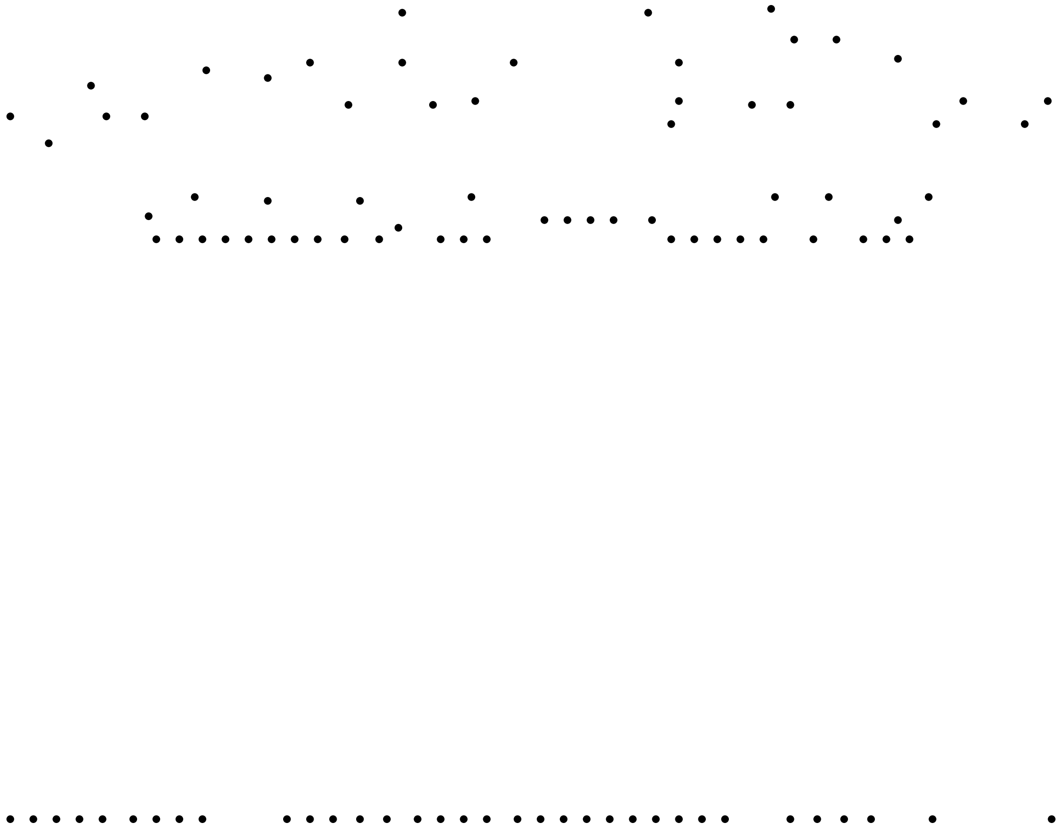


Figure C.20: Plated drill hit diagram

Appendix D

Study Materials

D.1 Activmon

The following participant information sheet, consent form and post-study questionnaire were provided to participants in the Activmon user study.

Private Bag 87 Hobart
Tasmania 7001 Australia
Phone (03) 6226 2900 Fax (03) 6226 2913
Email secretary@cis.utas.edu.au

UTAS

UNIVERSITY OF TASMANIA

PARTICIPANT INFORMATION SHEET
SOCIAL SCIENCE/ HUMANITITES
RESEARCH

Using Wearable Computers to Motivate Increased Physical Activity

Invitation
You are invited to participate in a research study into the use of wearable computers to encourage increased physical activity.

The study is being conducted by Professor Christopher Lueg and Patrick Burns of the University of Tasmania, and Dr. Shlomo Berkovsky of the CSIRO Tasmanian ICT Centre. The study is in partial fulfillment of the requirements of a PhD for Patrick Burns under the supervision of Prof. Lueg and Dr. Berkovsky.

1. 'What is the purpose of this study?'
The purpose of this study is to investigate whether wearable computer technologies might be effective in encouraging people to increase their daily level of physical activity.

2. 'Why have I been invited to participate in this study?'
Any adults who are able to engage in moderate physical activity are eligible to participate in this study.

4. 'What does this study involve?'
If you choose to participate in this study, we will ask you to wear an electronic device on your wrist which will monitor your level of physical activity. The device contains a motion sensor that is able to detect when you are moving around (walking, running, etc) and when you are not moving (sitting down working or watching TV). The device itself lights up a different colour depending on how much activity you have done during the day. Information on your level of physical activity will be stored in the device and periodically transmitted to the researchers via the Internet for analysis.

We may send general information about your level of physical activity to other participants in the study, and you may receive general information about the activity level of other participants. This information will be shared in an anonymous way. For example, your device may flash to show that other participants are being active, and their devices may flash in response to you being more active.

We will administer questionnaires during the study requesting general feedback on your experience using the device. These questionnaires might involve asking you how much physical activity you think you are doing, and how you feel about using the device.

During the study we may photograph or videorecord you with your permission. We will only use these photographs and videorecordings with your permission, and never in any way that could individually identify you. The data that we collect during this study may be published, however we will do this in a way that does not individually identify you.

It is important that you understand that your involvement in this study is voluntary. While we would be pleased to have you participate, we respect your right to decline. There will be no consequences to you if you decide not to participate. If you decide to discontinue participation at any time, you may do so without providing an explanation.

All information will be treated in a confidential manner, and your name will not be used in any publication arising out of the research. All of the research will be stored on secured computer systems prior to publication of the results, and then be archived to disc and stored in a locked cabinet in the office of Prof. Lueg.

5. Are there any possible benefits from participation in this study?
It is possible that by using the device you will be encouraged to become more active. A sustained increase in your level of physical activity could be beneficial for weight management and your overall health.

Information we collect from this study may help us to improve the wearable device, or help us design other technologies to motivate physical activity.

6. Are there any possible risks from participation in this study?

As with any physical activity, there is always a risk of injury. The first stage of the study involves only moderate physical activity, therefore we would expect the risk of injury is low. During the second and third stages of the study, the amount of activity you perform is up to you. However we would ask that you use your judgement in deciding on an appropriate level of activity.

If you have any medical condition or injury that might prevent you from performing moderate physical activity, we would advise you to seek advice from your doctor before participating. If you experience any pain or discomfort at any time during the study, you should discontinue what you are doing immediately, and advise the researchers. If you are not sure, consult your doctor.

7. What if I have questions about this research?

If you would like to discuss any aspect of this study please feel free to contact Patrick Burns at the University on (03) 6226 2324, or Prof. Lueg on (03) 6226 2911. We would be happy to discuss any aspect of the research with you. Once we have analysed the information we will be mailing / emailing you a summary of our findings. You are welcome to contact us at that time to discuss any issue relating to the research study.

This study has been approved by the Tasmanian Social Science Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study you should contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 7479 or email human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. You will need to quote reference number H0011645.

Thank you for taking the time to consider this study.
If you wish to take part in it, please sign the attached consent form.
This information sheet is for you to keep.

Private Bag 87 Hobart
Tasmania 7001 Australia
Phone (03) 6226 2900 Fax (03) 6226 2913
Email secretary@cis.utas.edu.au

UTAS

U N I V E R S I T Y O F T A S M A N I A

CONSENT FORM

Using Wearable Computers to Motivate Increased Physical Activity

1. I have read and understood the 'Information Sheet' for this project.
2. The nature and possible effects of the study have been explained to me.
3. I understand that the study involves monitoring of my level of physical activity using a wearable computer, and that information about my level of physical activity may be anonymously shared with other participants during the study. I understand that I will be asked questions about my experiences using the device, and my level of physical activity.
4. I understand that participation involves performing moderate-intensity physical activity, and that with any physical activity there is a risk of injury. I do not have any medical condition or injury that would prevent me from carrying out this activity, and have consulted my doctor if necessary. I understand that I should immediately discontinue any activity if I experience pain or discomfort.
5. I understand that all research data will be securely stored on the University of Tasmania premises for five years following publication, and will then be destroyed.
6. Any questions that I have asked have been answered to my satisfaction.
7. I agree that research data gathered from me for the study may be published provided that I cannot be identified as a participant.
8. I understand that the researchers will maintain my identity confidential and that any information I supply to the researcher(s) will be used only for the purposes of the research.
9. I agree to participate in this investigation and understand that I may withdraw at any time without any effect, and if I so wish, may request that any data I have supplied to date be withdrawn from the research.
10. I agree that the Investigators may photograph me during the study and that these photographs will not be used in any way that could identify me.

    Yes ☐ No ☐
11. I agree that the investigators may video record me during the study and that these video recordings will not be used in any way that could identify me.

    Yes ☐ No ☐

Continued over page

Name of Participant:

Signature: Date:

Statement by Investigator

☐ I have explained the project & the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked.

☐ The participant has received the Information Sheet where my details have been provided so participants have the opportunity to contact me prior to consenting to participate in this project.

Name of Investigator

Signature of Investigator

Name of investigator ______________________

Signature of investigator ______________________ Date ____________

ActivMON Questionnaire

Thank you for participating in the ActivMON study. We would like to hear about your experiences using the device.

Please answer honestly - your responses are anonymous.

We will be contacting you this week to arrange a short individual interview where you can give more detailed feedback if you wish.

* Required

Section A *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found ActivMON comfortable to wear.	○	○	○	○	○
The battery life was adequate.	○	○	○	○	○
It's inconvenient to have another device to charge.	○	○	○	○	○
ActivMON needs to be smaller.	○	○	○	○	○
I would use ActivMON if it helped me become more active/lose weight.	○	○	○	○	○

Section B *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I would like to choose my own colour scheme for the light.	○	○	○	○	○
I would like my doctor to have access to my activity data.	○	○	○	○	○
I was worried about what people would think if my light	○	○	○	○	○

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
was red.					
People (not in the study) asked me what I was wearing.					
I don't want others to know I'm monitoring my activity.					

Section C *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The ActivMON light was too bright.					
ActivMON got my attention when it started flashing.					
I had trouble understanding the colour.					
I wanted to see a graph of my progress.					
I wanted to to be able to turn off the light.					

Section D *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think I do enough physical activity.					
I thought the ActivMON goal (turning the light blue) was too easy.					
I wanted to do more physical activity to make the light go green.					
When I saw ActivMON flashing I thought about doing					

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
physical activity.					
ActivMON wouldn't change my existing habits.	○	○	○	○	○

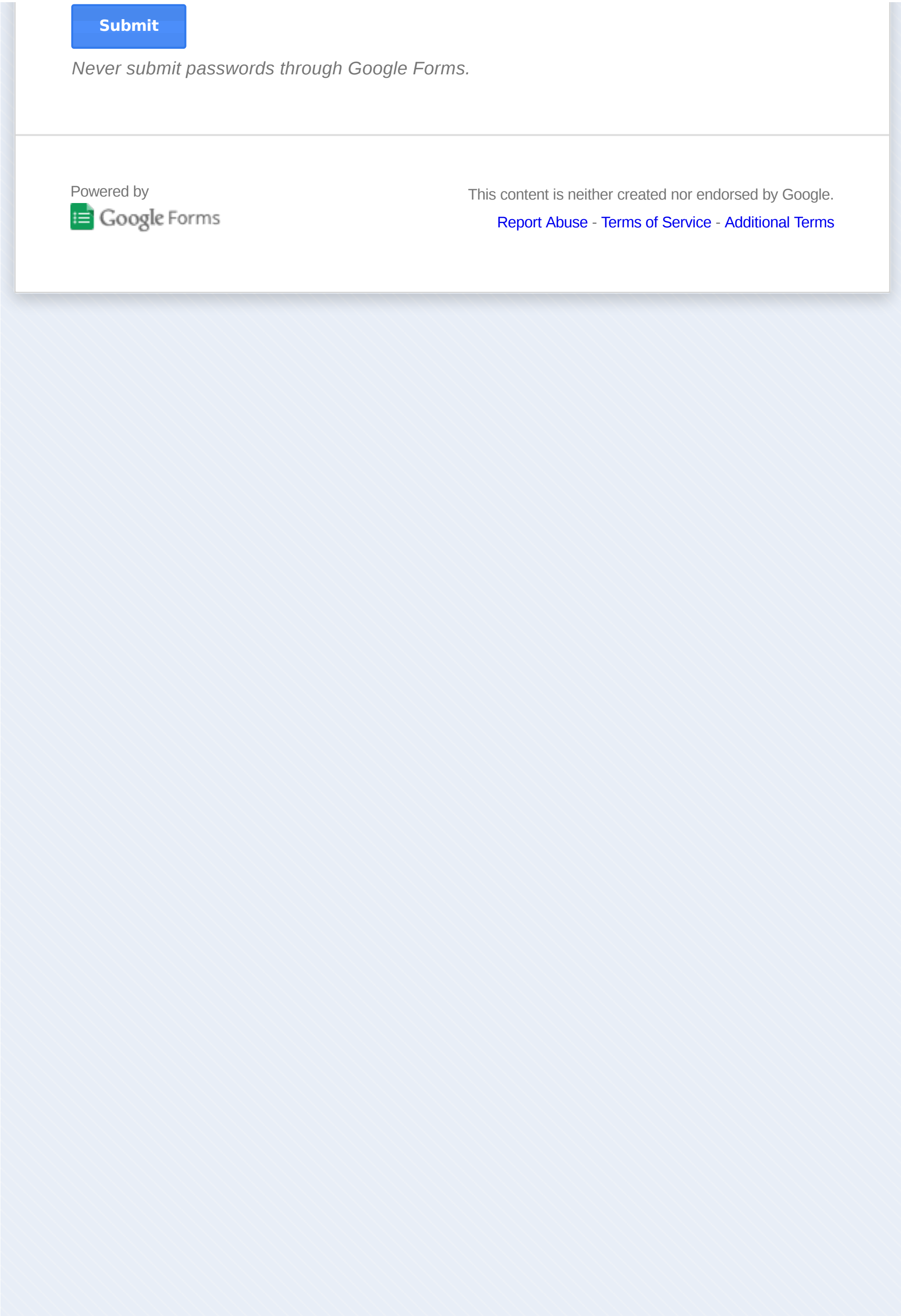
What form should the device take? (Choose as many options as you like.) *

- ☐ A separate bracelet (like it is now)
- ☐ Intergrated into a watch.
- ☐ A piece of jewellery.
- ☐ An item of clothing.
- ☐ A necklace.
- ☐ A shoe.
- ☐ Intergrated into a mobile phone.
- ☐ Other: ______

What did you like most about ActivMON? (Optional)

What did you find most frustrating about ActivMON? (Optional)

Do you have any suggestions about how ActivMON could be improved? (Optional)



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D.2 Activthings

In the Activthings user study, participants were provided with information and asked to complete questionnaires through an interactive website. The following are examples of those interactions.

D.2.1 Information, Consent and Eligibility

Prospective participants were provided with the following information, asked to complete a consent form (consent was recorded electronically), and asked to complete questions to determine their eligibility to participate.

Activthings

Thanks for your interest in Activthings. Unfortunately all of our research studies are now full and therefore closed to new participants. If you want to keep up to date with what we're working on, please join our mailing list.

Login

Existing participants please login below with your email address and the password you selected at registration.

email:

Password:

I forgot my password

Login

Hi there!

Thanks for your interest in being part of our research study. Many of us find it hard to stay active, especially when we are tired, busy or stressed. We know we need to get moving but it keeps getting pushed to the back of our minds. Sometimes it seems like it's all too much effort.

Knowing how well you're doing and where you need to go is the first step. We're looking at ways technology can make it simpler for people to keep track of how active they are. We have some good ideas, but we need your help to test them out. Have a read below to see what's involved and decide whether or not you want to sign up.

Being involved in this study might help you to reach some of your own health goals, and the things we learn from the study may help others in the future as well.

Who are we?

This study is operated by Patrick Burns and Christopher Lueg of the University of Tasmania and Shlomo Berkovsky of the CSIRO. Patrick receives a scholarship from UTAS and CSIRO to conduct this study as part of his PhD degree program. He is supervised by Christopher and Shlomo.

Who can be part of this study?

You can be part of this study if:

- You're living in Australia.
- Between 18-65 years old.
- Feel you're not active enough.
- Want to be more active.

Please let us know if you think your daily routine might change significantly in the next six months. For example:

- You're intending to travel.
- You're quitting or starting work or study.
- You're going into hospital or are having surgery done.

You need to own a mobile phone with Bluetooth and mobile Internet access.

Learn More

Page: **1** 2 3

This research project is jointly funded by the University of Tasmania and the CSIRO.

Activthings

What does this study involve?

First we'd like to ask you to spend 10-15 minutes online answering questions about how active you are, and how you feel about being active. We'll also ask about your age, gender, lifestyle and access to a mobile phone, to see whether you fit our requirements (shown on the previous page).

If we invite you to the next stage of the study, we'll provide you with a wrist-band that will monitor your daily activity (see the photo to the right). The wrist-band will tell us when you're moving around (walking, running) and when you're sitting still (working, watching TV). We'll ask you to wear the band every day, while you're awake, for about six weeks. The band has lights that will change colour to tell you how active you are. It will also connect to the Internet via your phone to tell us how active you've been.

We may tell others in the study how active you are, or tell you how active other people are. This will be done anonymously so other people in the study don't know your identity and you don't know theirs.

At the end of the study we'll ask you to spend 10-15 minutes online answering another set of questions. For example, how active you felt you were, how you feel about being active and how you felt wearing the band. You'll have a chance to give us your comments and feedback.

We may also invite you to participate in a 15-30 minute interview either in person, online or on the phone. In this interview we would ask you similar questions to those you answered online. For example, your level of activity, how you feel about being active and your thoughts and feelings about wearing the band.

Please note that your wristband may operate differently than in the introduction video. You may be shown only your own activity, only the activity of other people, or both. Even if your friends, family or colleagues are also participating in the study there is no guarantee you will be able to compete with them - you may be assigned to a group of people you don't know.

Login

Existing participants please login below with your email address and the password you selected at registration.

email:

Password:

I forgot my password

Login

What happens to the information you collect?

Your answers to questions before and after the study, as well as activity information collected by your wrist-band, will be stored in a secure computer database. Your activity information may be shared with others in the study, in a way that doesn't identify you.

During the study we will also need to store your name, address, phone number and email address. This is so that we can keep in contact with you and provide you with technical support. Your identity can only be seen by the three researchers and will not be shared with anyone else.

After the study your name, address, phone number and email address will be deleted. We will keep your activity information, questionnaire answers, interview responses and comments but will remove your name from them. We may later publish this information but we will make sure you cannot be personally identified.

After we publish the results of the study we will store them for five years. After five years they will be destroyed.

What are the benefits for me?

You may learn more about your own level of daily activity. You might find this helps you to make better choices that lead to you becoming more healthy and active. Also you'll know that your participation has provided us with information that could allow us to help others to reach their own health goals.

As an extra thank-you for your time and effort, if you complete the study you'll be entered into a draw to win an iPad ($539 value). The winner will be drawn at random at the end of the study.

Learn More

Page: 1 **2** 3

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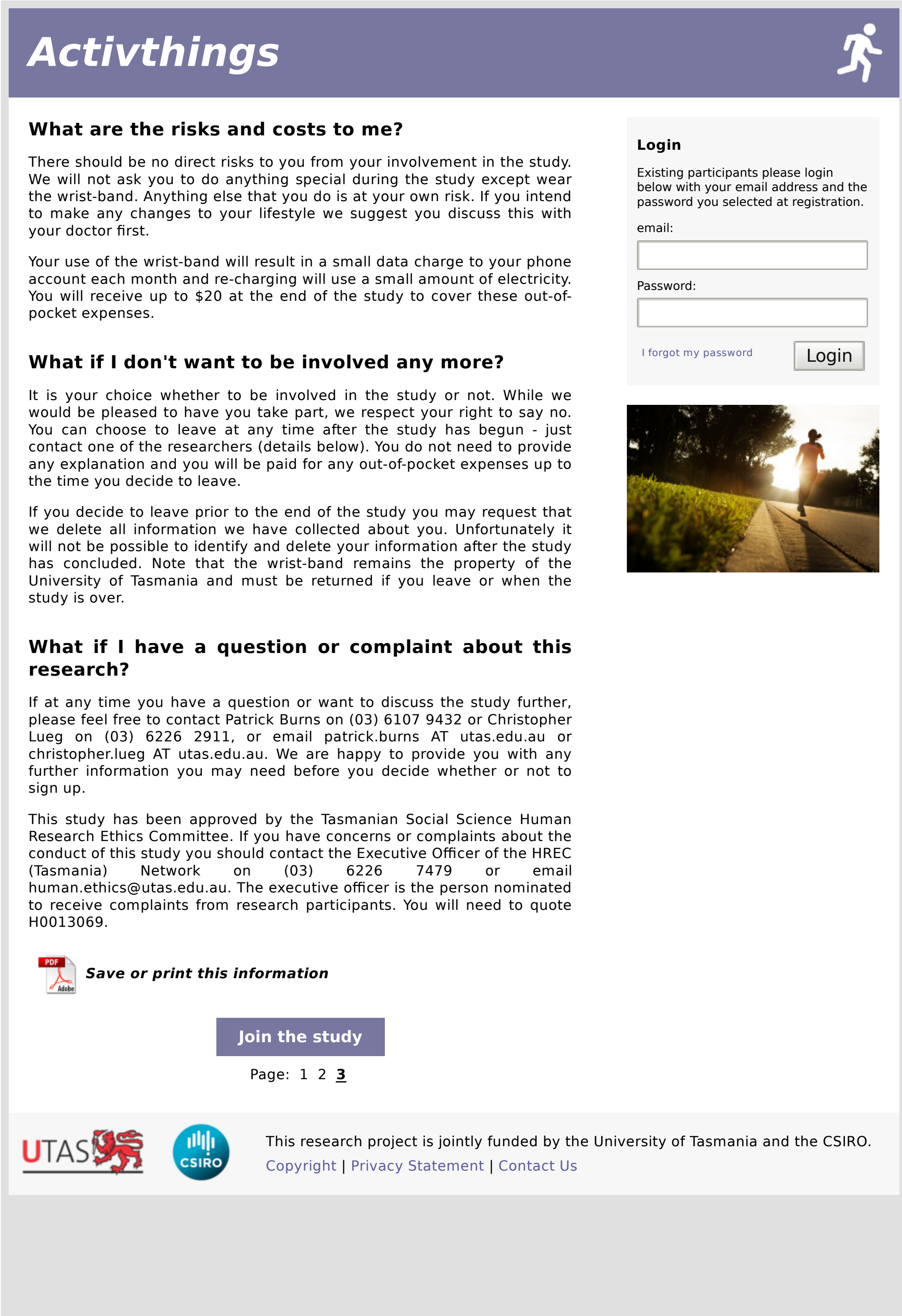

Activthings

What are the risks and costs to me?

There should be no direct risks to you from your involvement in the study. We will not ask you to do anything special during the study except wear the wrist-band. Anything else that you do is at your own risk. If you intend to make any changes to your lifestyle we suggest you discuss this with your doctor first.

Your use of the wrist-band will result in a small data charge to your phone account each month and re-charging will use a small amount of electricity. You will receive up to $20 at the end of the study to cover these out-of-pocket expenses.

What if I don't want to be involved any more?

It is your choice whether to be involved in the study or not. While we would be pleased to have you take part, we respect your right to say no. You can choose to leave at any time after the study has begun - just contact one of the researchers (details below). You do not need to provide any explanation and you will be paid for any out-of-pocket expenses up to the time you decide to leave.

If you decide to leave prior to the end of the study you may request that we delete all information we have collected about you. Unfortunately it will not be possible to identify and delete your information after the study has concluded. Note that the wrist-band remains the property of the University of Tasmania and must be returned if you leave or when the study is over.

What if I have a question or complaint about this research?

If at any time you have a question or want to discuss the study further, please feel free to contact Patrick Burns on (03) 6107 9432 or Christopher Lueg on (03) 6226 2911, or email patrick.burns AT utas.edu.au or christopher.lueg AT utas.edu.au. We are happy to provide you with any further information you may need before you decide whether or not to sign up.

This study has been approved by the Tasmanian Social Science Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study you should contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 7479 or email human.ethics@utas.edu.au. The executive officer is the person nominated to receive complaints from research participants. You will need to quote H0013069.

Save or print this information

Join the study

Page: 1 2 **3**

Login

Existing participants please login below with your email address and the password you selected at registration.

email:

Password:

I forgot my password

Login

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Activthings

Thanks for your interest!

Thanks for wanting to be part of our research study. To join you'll need to complete the following consent form, create an account with our website, and spend about ten minutes answering some simple questions. If you're ready we can start the process now. Otherwise, if you're busy now or want more time to consider the information you've just read, feel free to leave and come back later.

Consent Form

Please read the following carefully.

- I have read and understood the participant information for this study. I understand that the study involves monitoring my physical activity using an electronic wrist-band for a period of approximately four weeks.
- I understand that I will be asked questions about my level of activity and my feelings toward physical activity before and after the study. I will be asked questions about my experiences and thoughts of using the wrist band after the study.
- I understand that there are no direct risks to me from my participation in the study. I am not being asked to perform any particular activity apart from wearing the wrist-band. I will consult my doctor if necessary before making any lifestyle changes.
- I understand that all information collected will be stored securely at the University of Tasmania for five years following publication of results, and will then be destroyed.
- I have had an opportunity to ask questions and to have them answered to my satisfaction.
- I agree that all information collected from me may be published, provided that I cannot be identified as a participant.
- I understand that the researchers will keep my identity confidential and that all information I supply to the researchers will be used only for the purposes of this study. I may make a request to access my information at any time before the end of the study.
- I agree to participate in this study. I understand that I may leave at any time and that I will still be paid for any out-of-pocket expenses. If I leave before the end of the study I may request that all information I have supplied be deleted.

If you agree with the above, please type your full name into the box below to show your acceptance.

I, Sample Participant **have read and understood the above and agree to participate in the Activthings research study.**

Continue

Login

Existing participants please login below with your email address and the password you selected at registration.

email:

Password:

I forgot my password

Login

Registration Progress

- Consent
- Initial questions
- Personal information
- Current activity
- Activity inventory
- Done!

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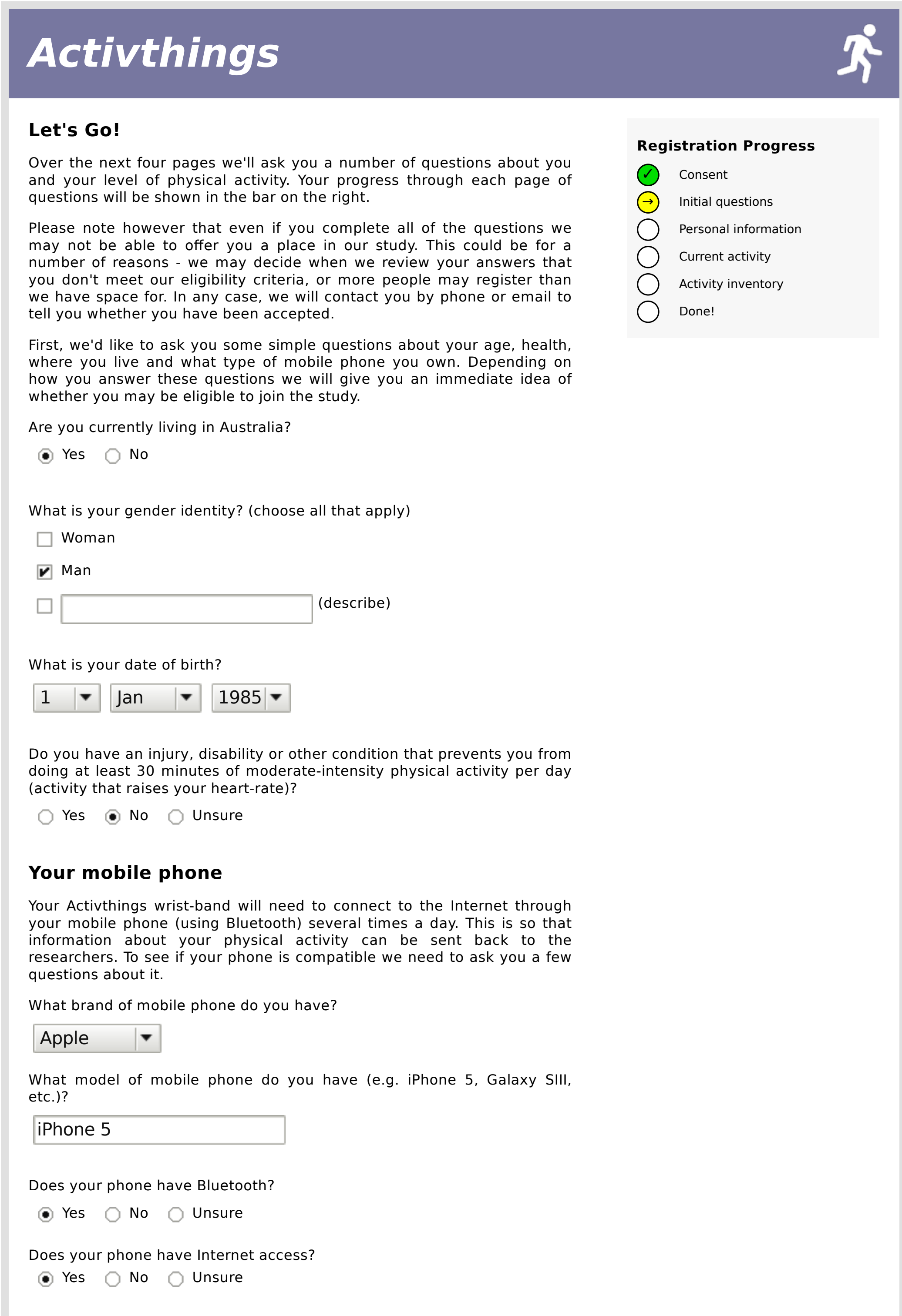

Activthings

Let's Go!

Over the next four pages we'll ask you a number of questions about you and your level of physical activity. Your progress through each page of questions will be shown in the bar on the right.

Please note however that even if you complete all of the questions we may not be able to offer you a place in our study. This could be for a number of reasons - we may decide when we review your answers that you don't meet our eligibility criteria, or more people may register than we have space for. In any case, we will contact you by phone or email to tell you whether you have been accepted.

First, we'd like to ask you some simple questions about your age, health, where you live and what type of mobile phone you own. Depending on how you answer these questions we will give you an immediate idea of whether you may be eligible to join the study.

Are you currently living in Australia?

Yes No

What is your gender identity? (choose all that apply)

Woman

Man

(describe)

What is your date of birth?

1 Jan 1985

Do you have an injury, disability or other condition that prevents you from doing at least 30 minutes of moderate-intensity physical activity per day (activity that raises your heart-rate)?

Yes No Unsure

Your mobile phone

Your Activthings wrist-band will need to connect to the Internet through your mobile phone (using Bluetooth) several times a day. This is so that information about your physical activity can be sent back to the researchers. To see if your phone is compatible we need to ask you a few questions about it.

What brand of mobile phone do you have?

Apple

What model of mobile phone do you have (e.g. iPhone 5, Galaxy SIII, etc.)?

iPhone 5

Does your phone have Bluetooth?

Yes No Unsure

Does your phone have Internet access?

Yes No Unsure

Registration Progress

- Consent
- Initial questions
- Personal information
- Current activity
- Activity inventory
- Done!

Are you on a monthly phone plan or prepaid?

○ A monthly plan ◉ Prepaid ○ Unsure

The Activthings device will connect to the Internet through your mobile phone several times a day. As a result you may receive a small additional charge to your phone account. You will receive up to $20 to cover these extra charges. Please note that we cannot be responsible for other data usage charges (due to updates, app activity etc.) that you may incur as a result of having Internet access enabled during the study.

Continue

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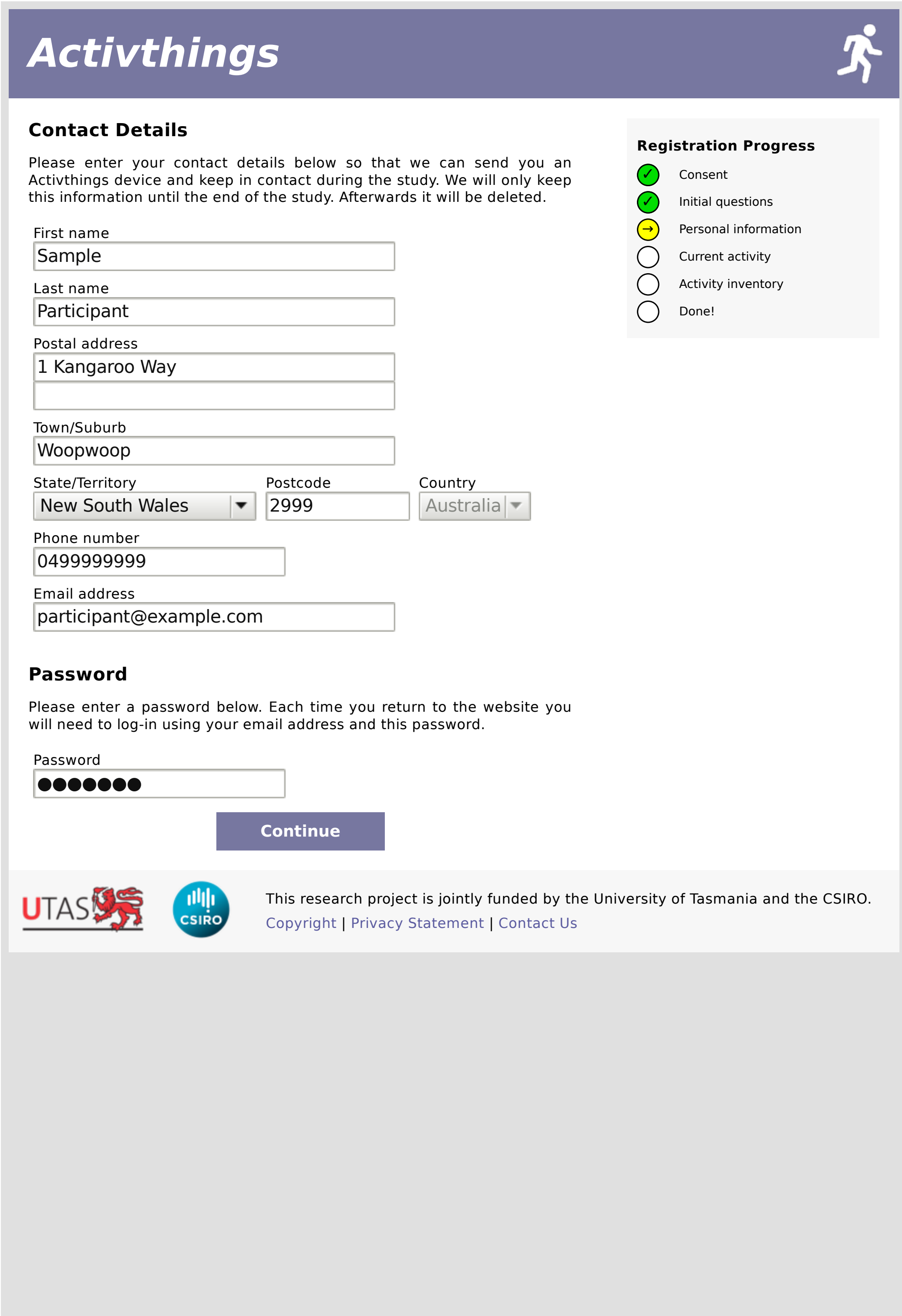

Activthings

Contact Details

Please enter your contact details below so that we can send you an Activthings device and keep in contact during the study. We will only keep this information until the end of the study. Afterwards it will be deleted.

First name
Sample

Last name
Participant

Postal address
1 Kangaroo Way

Town/Suburb
Woopwoop

State/Territory
New South Wales

Postcode
2999

Country
Australia

Phone number
0499999999

Email address
participant@example.com

Password

Please enter a password below. Each time you return to the website you will need to log-in using your email address and this password.

Password
●●●●●●●

Continue

Registration Progress

- Consent
- Initial questions
- Personal information
- Current activity
- Activity inventory
- Done!

UTAS

CSIRO

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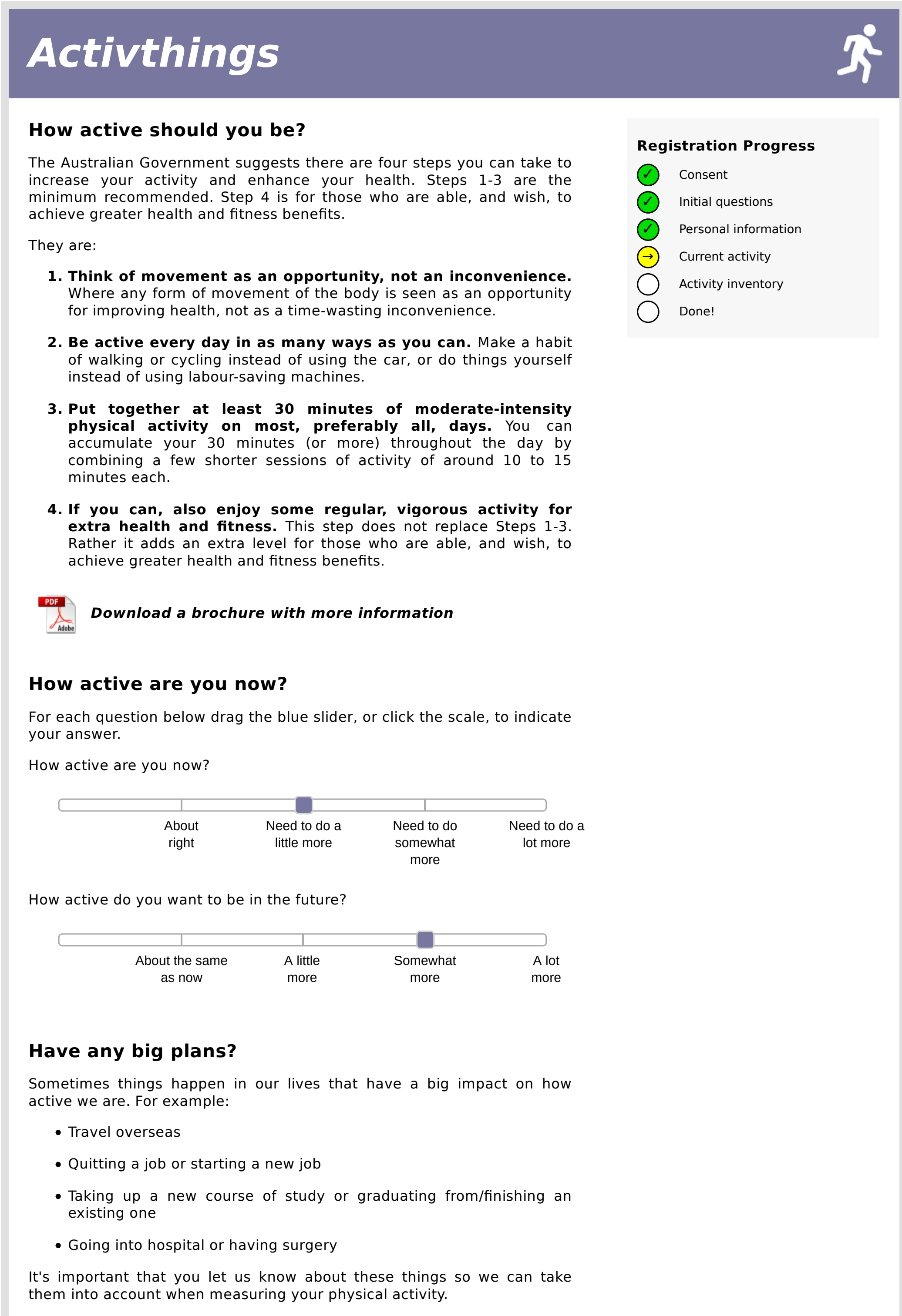

Activthings

How active should you be?

The Australian Government suggests there are four steps you can take to increase your activity and enhance your health. Steps 1-3 are the minimum recommended. Step 4 is for those who are able, and wish, to achieve greater health and fitness benefits.

They are:

1. **Think of movement as an opportunity, not an inconvenience.** Where any form of movement of the body is seen as an opportunity for improving health, not as a time-wasting inconvenience.
2. **Be active every day in as many ways as you can.** Make a habit of walking or cycling instead of using the car, or do things yourself instead of using labour-saving machines.
3. **Put together at least 30 minutes of moderate-intensity physical activity on most, preferably all, days.** You can accumulate your 30 minutes (or more) throughout the day by combining a few shorter sessions of activity of around 10 to 15 minutes each.
4. **If you can, also enjoy some regular, vigorous activity for extra health and fitness.** This step does not replace Steps 1-3. Rather it adds an extra level for those who are able, and wish, to achieve greater health and fitness benefits.

Download a brochure with more information

Registration Progress

- Consent
- Initial questions
- Personal information
- Current activity
- Activity inventory
- Done!

How active are you now?

For each question below drag the blue slider, or click the scale, to indicate your answer.

How active are you now?

About right | Need to do a little more | Need to do somewhat more | Need to do a lot more

How active do you want to be in the future?

About the same as now | A little more | Somewhat more | A lot more

Have any big plans?

Sometimes things happen in our lives that have a big impact on how active we are. For example:

- Travel overseas
- Quitting a job or starting a new job
- Taking up a new course of study or graduating from/finishing an existing one
- Going into hospital or having surgery

It's important that you let us know about these things so we can take them into account when measuring your physical activity.

☑ I don't expect any big changes to happen during the study (please tick)

OR

Something is happening that could affect my activity level (please describe below)

Continue

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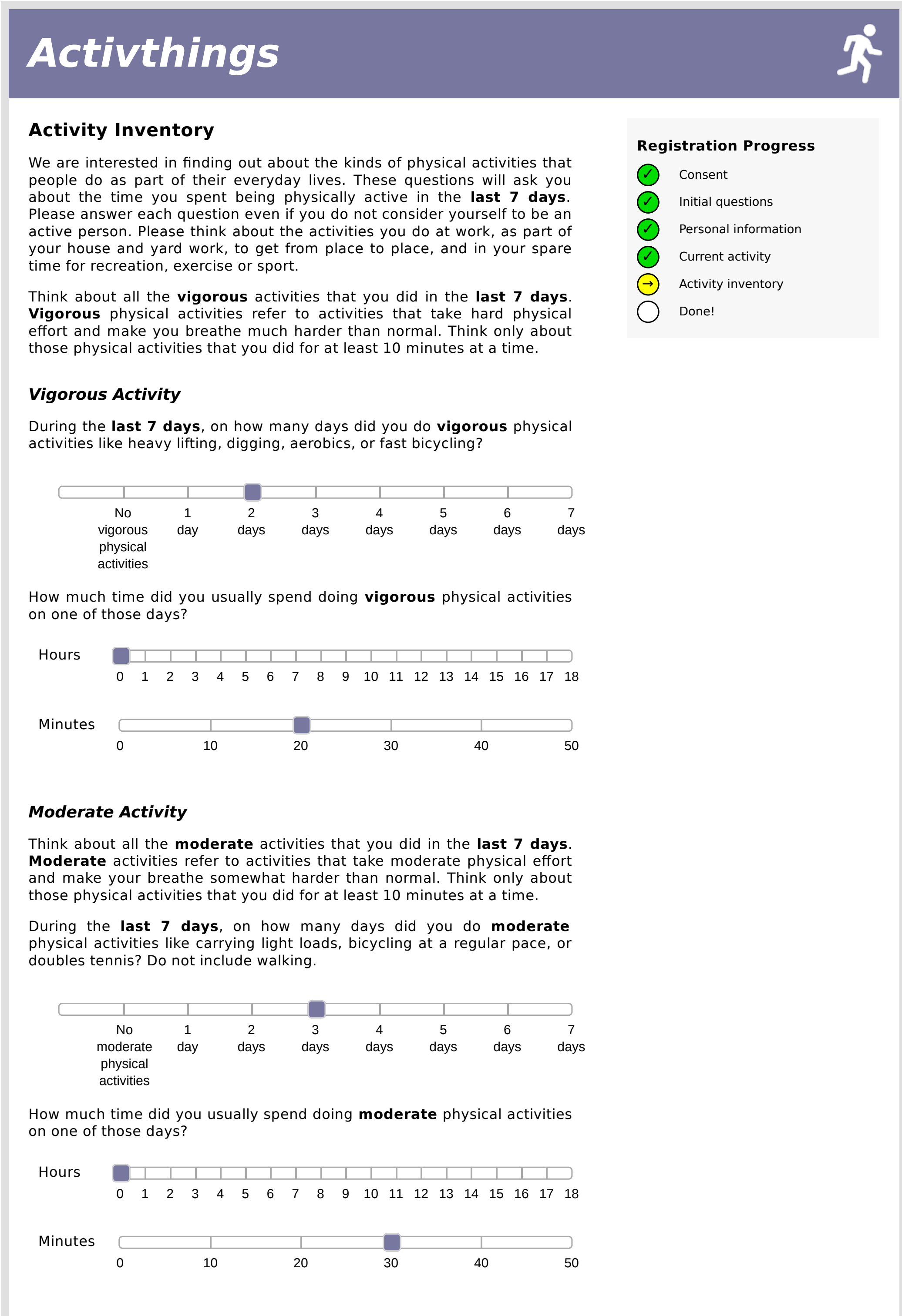

Activthings

Activity Inventory

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. These questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

Vigorous Activity

During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

No vigorous physical activities | 1 day | 2 days | 3 days | 4 days | 5 days | 6 days | 7 days

How much time did you usually spend doing **vigorous** physical activities on one of those days?

Hours 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes 0 10 20 30 40 50

Moderate Activity

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make your breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

No moderate physical activities | 1 day | 2 days | 3 days | 4 days | 5 days | 6 days | 7 days

How much time did you usually spend doing **moderate** physical activities on one of those days?

Hours 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes 0 10 20 30 40 50

Registration Progress

- Consent
- Initial questions
- Personal information
- Current activity
- Activity inventory
- Done!

Walking

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise or leisure.

During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

No walking	1 day	2 days	3 days	4 days	5 days	6 days	7 days

How much time did you usually spend **walking** on one of those days?

Hours
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes
0 10 20 30 40 50

Sitting

The last question is about the time you spent sitting on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

Hours
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes
0 10 20 30 40 50

Continue

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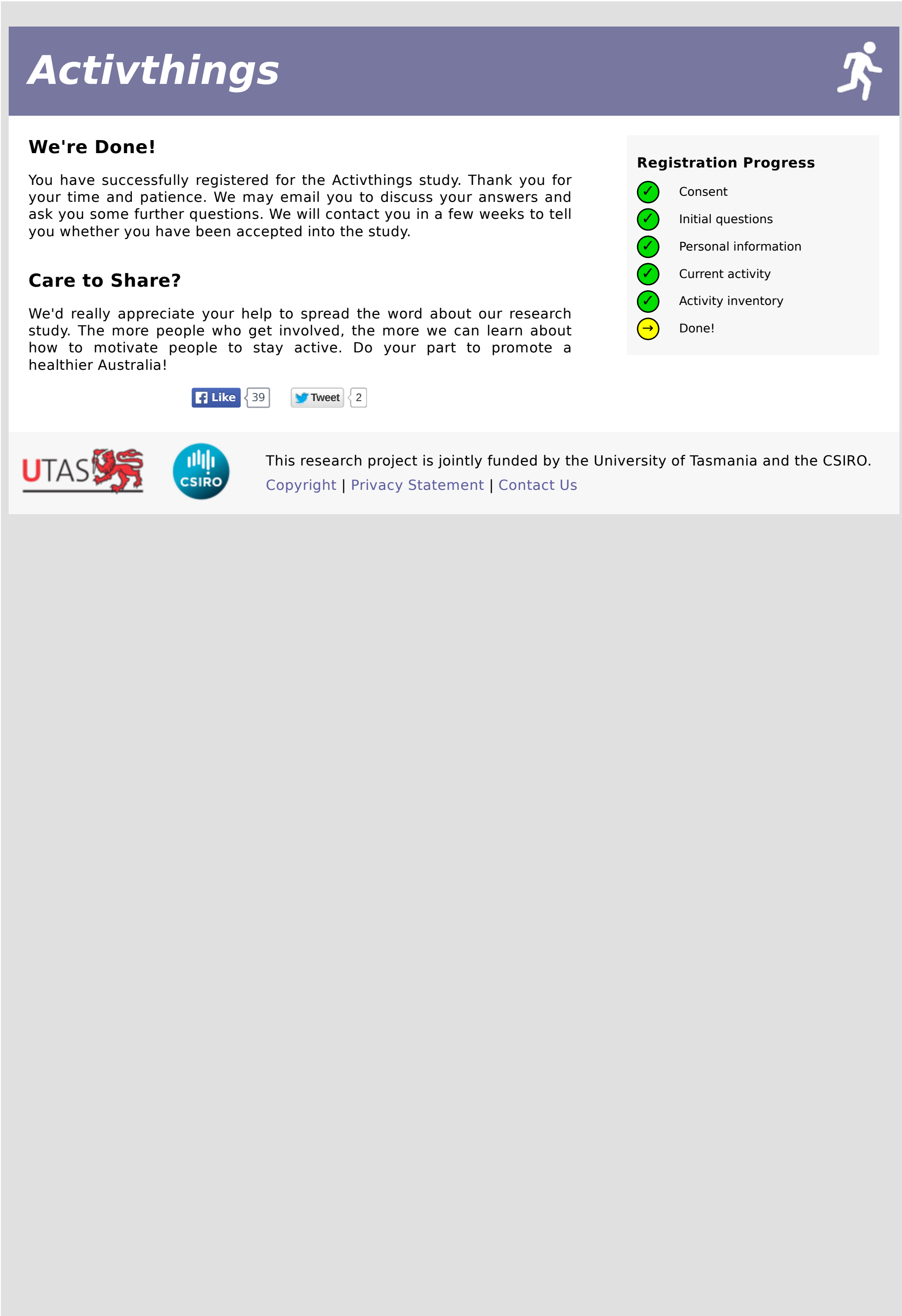

Activthings

We're Done!

You have successfully registered for the Activthings study. Thank you for your time and patience. We may email you to discuss your answers and ask you some further questions. We will contact you in a few weeks to tell you whether you have been accepted into the study.

Care to Share?

We'd really appreciate your help to spread the word about our research study. The more people who get involved, the more we can learn about how to motivate people to stay active. Do your part to promote a healthier Australia!

Like 39 Tweet 2

Registration Progress

- Consent
- Initial questions
- Personal information
- Current activity
- Activity inventory
- Done!

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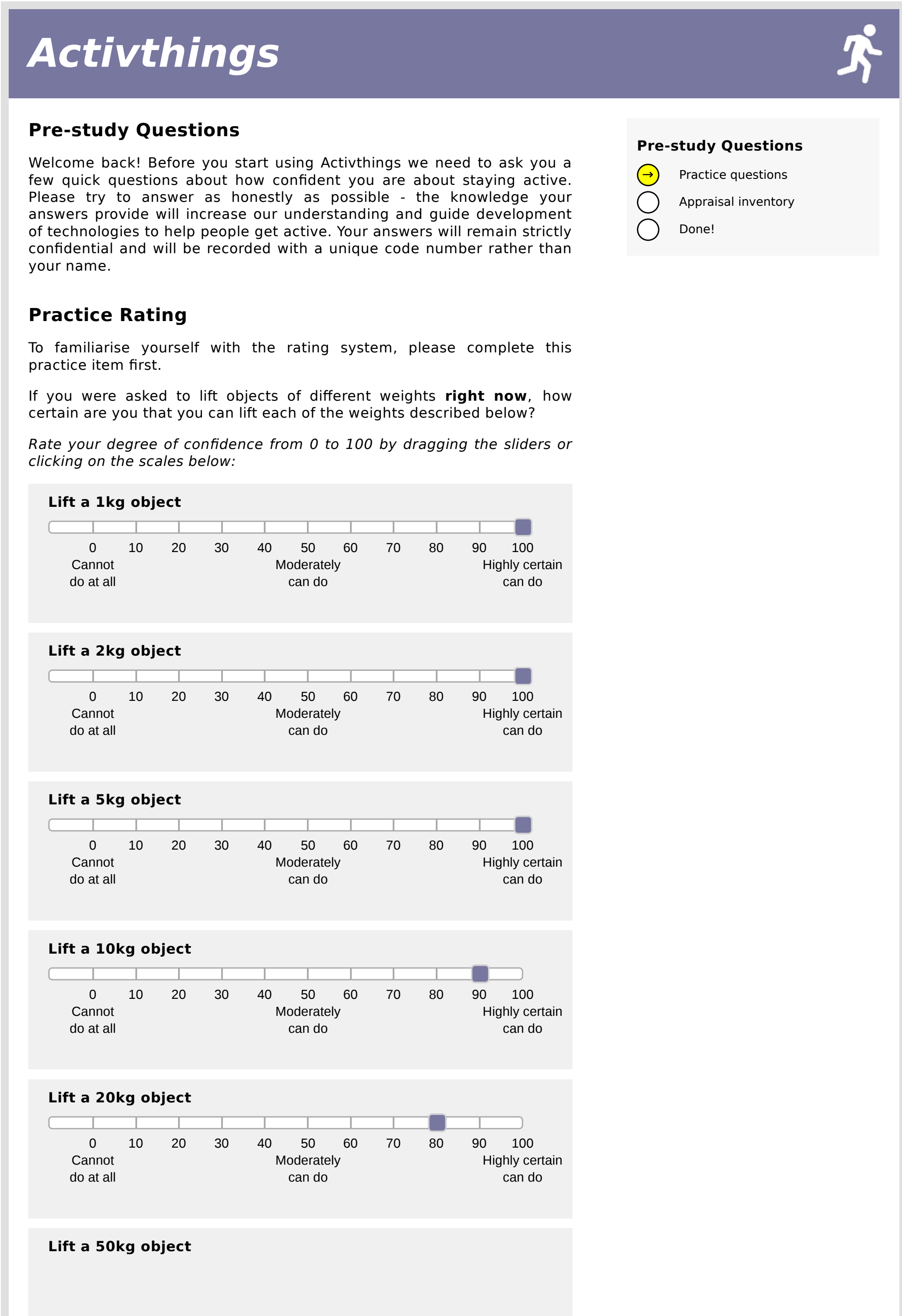
D.2.2 Pre-Study Questions

Participants who were selected to participate in the study were asked to complete the following questions before wearing the Activthings device.



Activthings

Pre-study Questions

Welcome back! Before you start using Activthings we need to ask you a few quick questions about how confident you are about staying active. Please try to answer as honestly as possible - the knowledge your answers provide will increase our understanding and guide development of technologies to help people get active. Your answers will remain strictly confidential and will be recorded with a unique code number rather than your name.

Practice Rating

To familiarise yourself with the rating system, please complete this practice item first.

If you were asked to lift objects of different weights **right now**, how certain are you that you can lift each of the weights described below?

Rate your degree of confidence from 0 to 100 by dragging the sliders or clicking on the scales below:

Lift a 1kg object

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

Lift a 2kg object

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

Lift a 5kg object

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

Lift a 10kg object

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

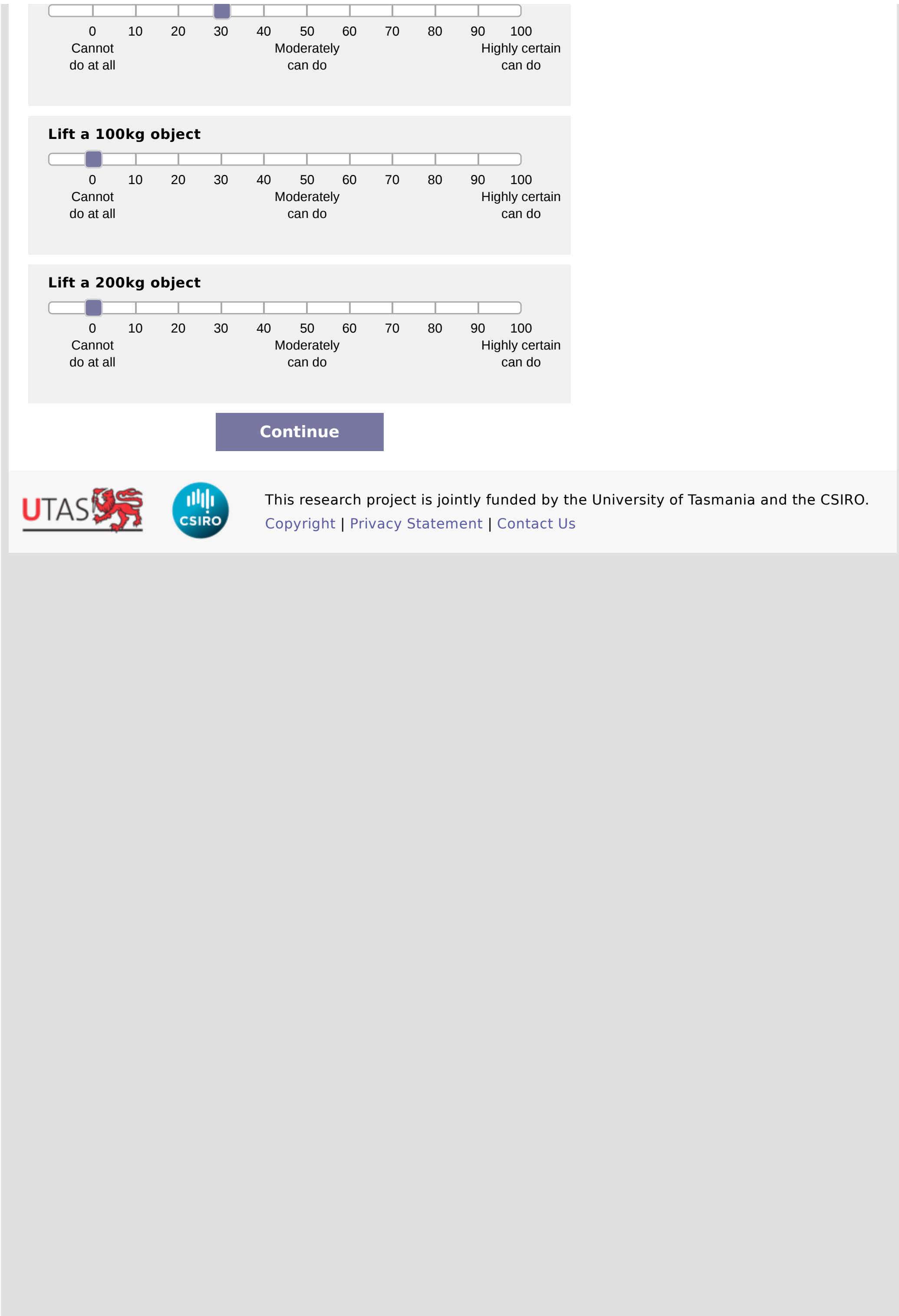
Lift a 20kg object

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

Lift a 50kg object

Pre-study Questions

- Practice questions
- Appraisal inventory
- Done!


0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
Lift a 100kg object
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
Lift a 200kg object
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
Continue
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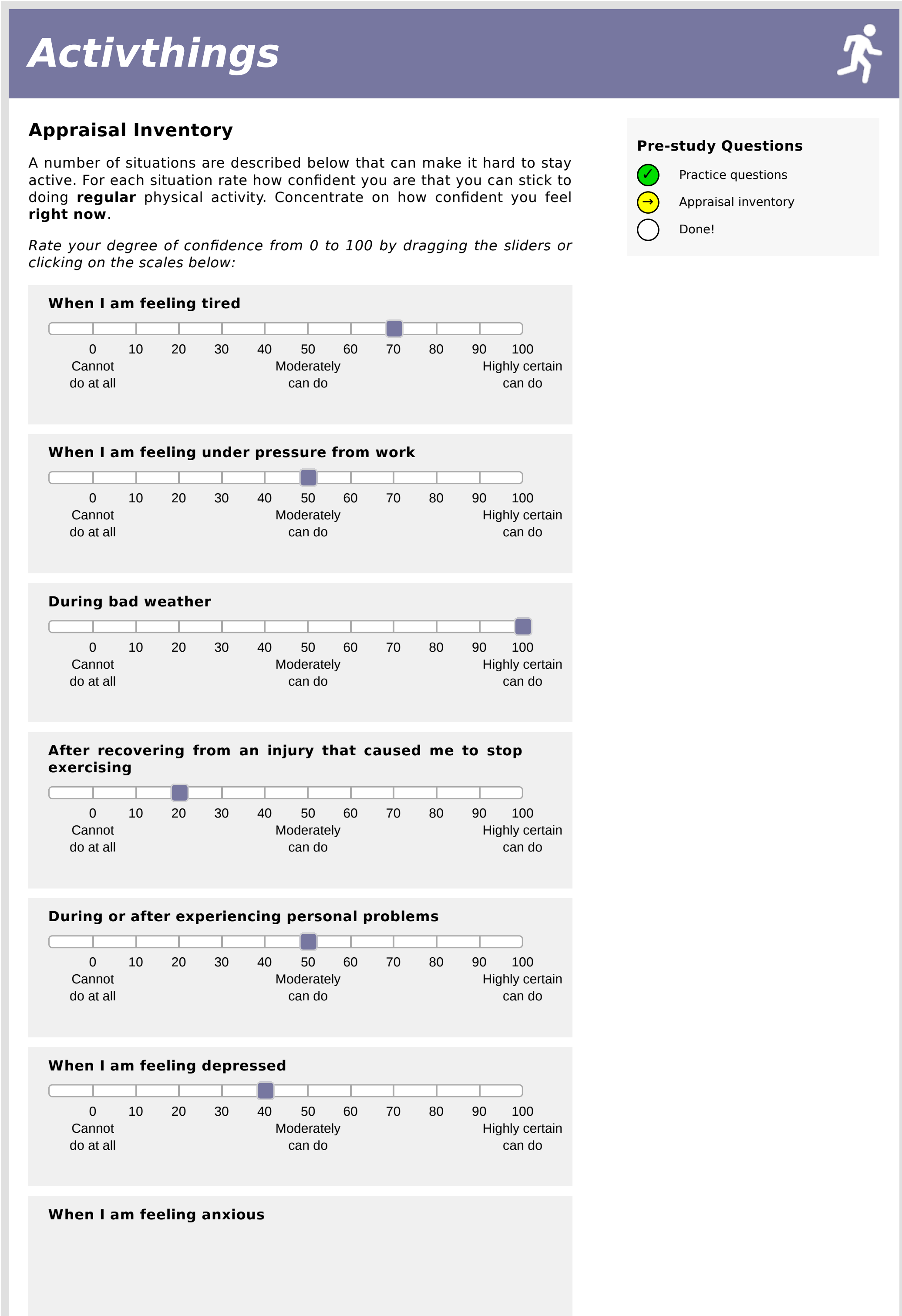
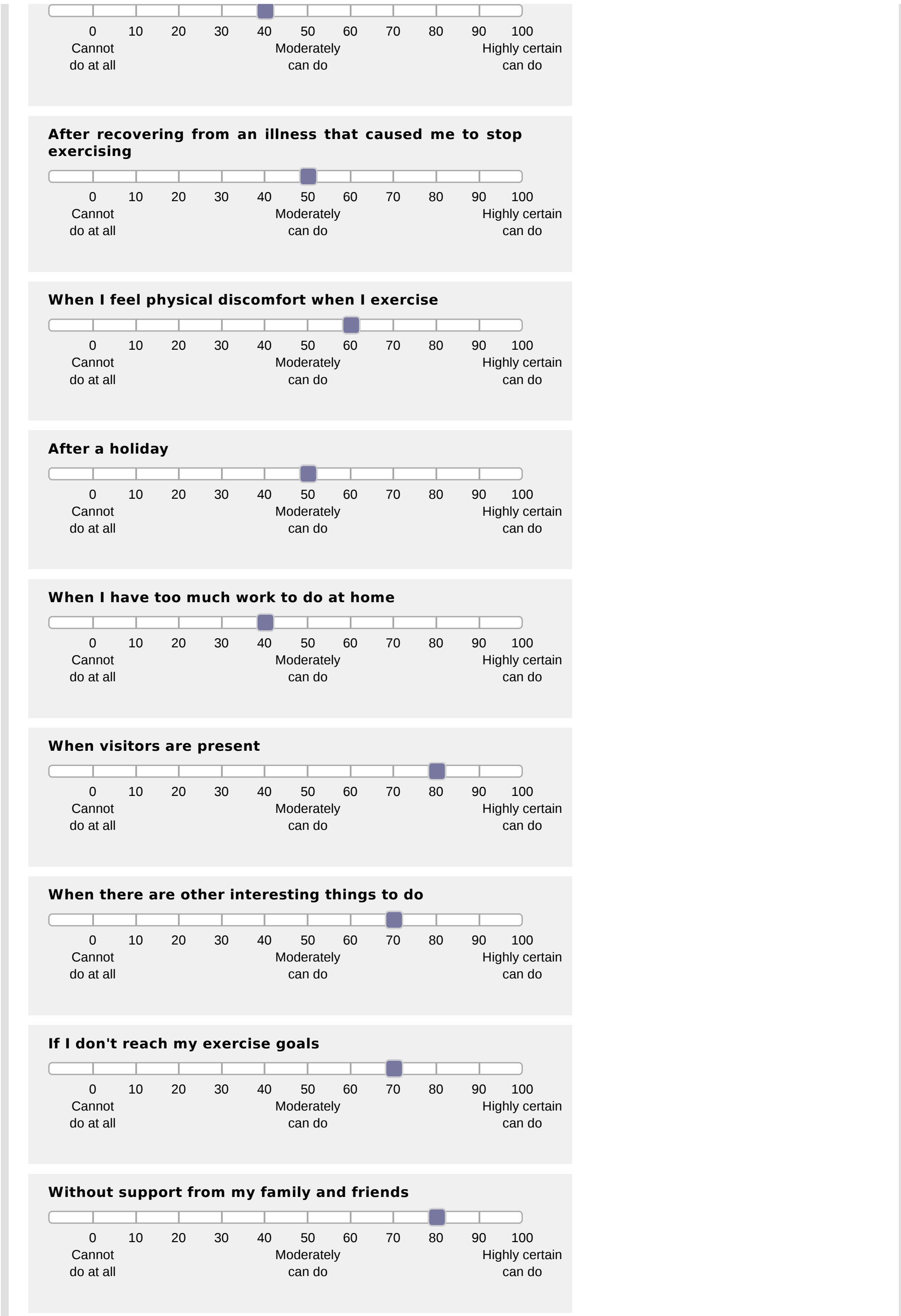
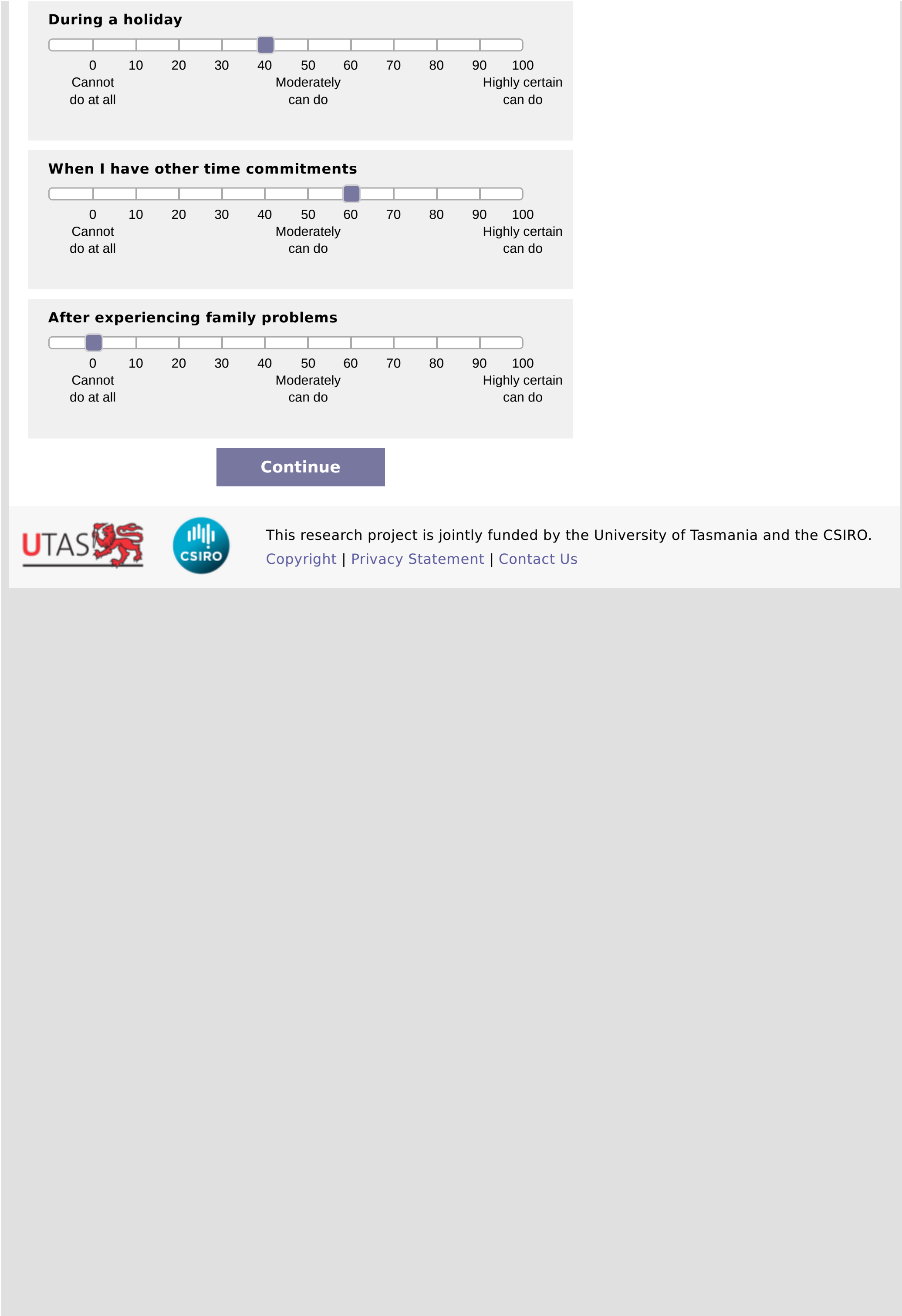

Activthings
Appraisal Inventory
A number of situations are described below that can make it hard to stay active. For each situation rate how confident you are that you can stick to doing regular physical activity. Concentrate on how confident you feel right now.
Rate your degree of confidence from 0 to 100 by dragging the sliders or clicking on the scales below:
When I am feeling tired
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I am feeling under pressure from work
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
During bad weather
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
After recovering from an injury that caused me to stop exercising
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
During or after experiencing personal problems
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I am feeling depressed
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I am feeling anxious
Pre-study Questions
Practice questions
Appraisal inventory
Done!


0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
After recovering from an illness that caused me to stop exercising
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I feel physical discomfort when I exercise
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
After a holiday
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I have too much work to do at home
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When visitors are present
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When there are other interesting things to do
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
If I don't reach my exercise goals
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
Without support from my family and friends
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do



During a holiday

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

When I have other time commitments

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

After experiencing family problems

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

Continue

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Activthings
We're Done!
Thank you for your answers. Your Activthings wristband will be on its way soon.
Pre-study Questions
Practice questions
Appraisal inventory
Done!
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D.2.3 Post-Study Questions

Participants were asked to complete the following questions at the end of the Activthings study. The first page presented different questions depending on whether the participant had worn the device or not. Both possible pages are provided below.

Activthings

Thanks!

Thank you for your participation in the Activthings study. We'd now like to ask you some questions about how you went during the six week study period. We understand that Activthings isn't for everyone and you may have decided not to start the study, to stop wearing the band or to leave before the end. We also appreciate that life is unpredictable and things may have happened that made it difficult for you to participate. Perhaps there was a technical problem with your device or phone we weren't able to resolve for you.

No matter what happened we still value your feedback. Everything you tell us, both good and bad, will help us to understand how to design better technology to motivate people to stay active. We may publish any or all of the answers you provide but we promise to do this in a way that doesn't identify you individually. You will remain anonymous, so please give us your honest opinions.

Questionnaire Progress

- Usage
- Perceptions
- Appraisal Inventory
- Activity Inventory
- Comments
- Payment
- Done!

Your Use of Activthings

First, a few short questions about your use of Activthings

Did you wear the Activthings wrist band?

- ○ Yes
- ◉ No

For the purposes of our research it's important for us to understand the reasons why people use Activthings as well as the reasons people don't use Activthings. For you, what are the reasons you decided not to use Activthings or stopped using it?

Continue

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Activthings

Thanks!

Thank you for your participation in the Activthings study. We'd now like to ask you some questions about how you went during the six week study period. We understand that Activthings isn't for everyone and you may have decided not to start the study, to stop wearing the band or to leave before the end. We also appreciate that life is unpredictable and things may have happened that made it difficult for you to participate. Perhaps there was a technical problem with your device or phone we weren't able to resolve for you.

No matter what happened we still value your feedback. Everything you tell us, both good and bad, will help us to understand how to design better technology to motivate people to stay active. We may publish any or all of the answers you provide but we promise to do this in a way that doesn't identify you individually. You will remain anonymous, so please give us your honest opinions.

Questionnaire Progress

- → Usage
- Perceptions
- Appraisal Inventory
- Activity Inventory
- Comments
- Payment
- Done!

Your Use of Activthings

First, a few short questions about your use of Activthings

Did you wear the Activthings wrist band?

- (•) Yes
- ( ) No

We suggested you wear Activthings on your wrist, but we understand you may have worn it elsewhere on your body some or all of the time. Where did you wear or carry Activthings **while it was switched on?** Tick all that apply:

- [x] Wrist/Lower Arm
- [ ] Upper Arm
- [ ] Chest
- [ ] Neck
- [ ] Upper Leg
- [ ] Ankle/Lower Leg
- [ ] Foot/Shoe
- [x] Waist/Belt
- [ ] Chest Pocket
- [x] Waist Pocket
- [ ] Leg Pocket
- [ ] In a Bag

Where did you wear or carry Activthings while it was switched on, most of the time? Choose the best answer:

- ( ) Wrist/Lower Arm
- (•) Upper Arm
- ( ) Chest
- ( ) Neck
- ( ) Upper Leg

- ◯ Ankle/Lower Leg
- ◯ Foot/Shoe
- ◯ Waist/Belt
- ◯ Chest Pocket
- ◯ Waist Pocket
- ◯ Leg Pocket
- ◯ In a Bag

Did you stop wearing Activthings before the end of the study (sooner than six weeks after you first wore it)?

- ◯ Yes
- ◉ No

Now that the study is over we'd like you to return Activthings to us. If you could choose to keep wearing Activthings, would you?

◉ Yes ◯ No

Thinking about the days you **did wear** Activthings, were there any particular reasons why you did or could wear it?

Thinking about the days you **didn't wear** Activthings, were there any particular reasons why you didn't or couldn't wear it?

Usability

Now we'd like to ask you some questions about how you felt using and wearing Activthings. Please drag the slider or click on the bar to indicate how much you agree or disagree with each statement.

It was easy to connect Activthings to my phone

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

Activthings was comfortable to wear

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I enjoyed wearing Activthings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

People noticed I was wearing Activthings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I felt embarassed wearing Activthings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

People asked me awkward questions about Activthings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I remembered to wear Activthings most days

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I remembered to charge Activthings most days

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

Charging Activthings was inconvenient

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

The battery didn't last long enough

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

Continue

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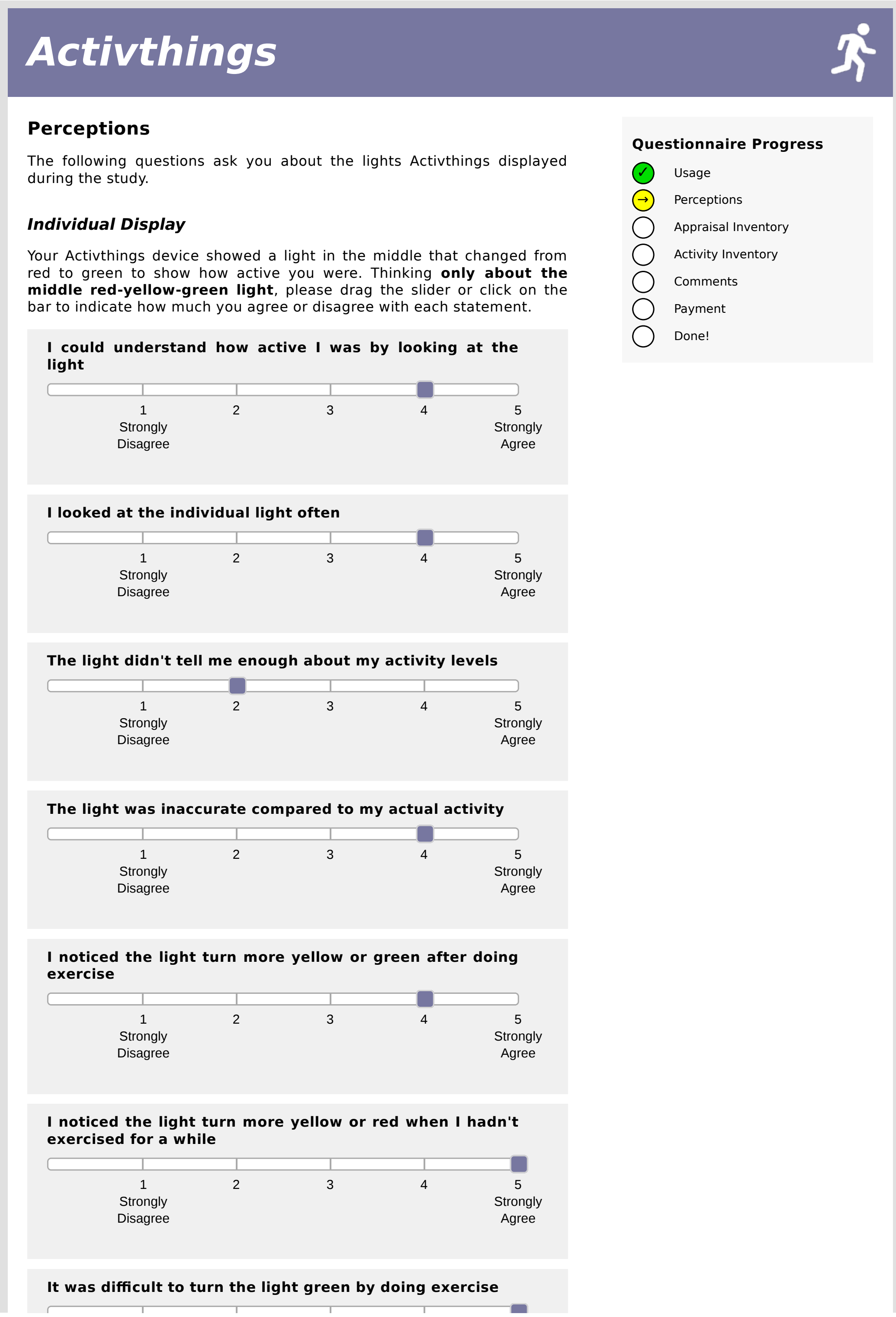


Activthings

Perceptions

The following questions ask you about the lights Activthings displayed during the study.

Individual Display

Your Activthings device showed a light in the middle that changed from red to green to show how active you were. Thinking **only about the middle red-yellow-green light**, please drag the slider or click on the bar to indicate how much you agree or disagree with each statement.

I could understand how active I was by looking at the light

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I looked at the individual light often

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

The light didn't tell me enough about my activity levels

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

The light was inaccurate compared to my actual activity

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I noticed the light turn more yellow or green after doing exercise

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I noticed the light turn more yellow or red when I hadn't exercised for a while

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

It was difficult to turn the light green by doing exercise

Questionnaire Progress

- Usage
- Perceptions
- Appraisal Inventory
- Activity Inventory
- Comments
- Payment
- Done!

Strongly Disagree — Strongly Agree

The light turned red quickly when I didn't exercise

1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree

It was a fair challenge trying to turn the light green

1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree

I didn't care what colour the light was

1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree

I wanted to be able to set my own activity goals

1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree

I wanted to see steps/distance/calories

1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree

I didn't feel motivated by the light

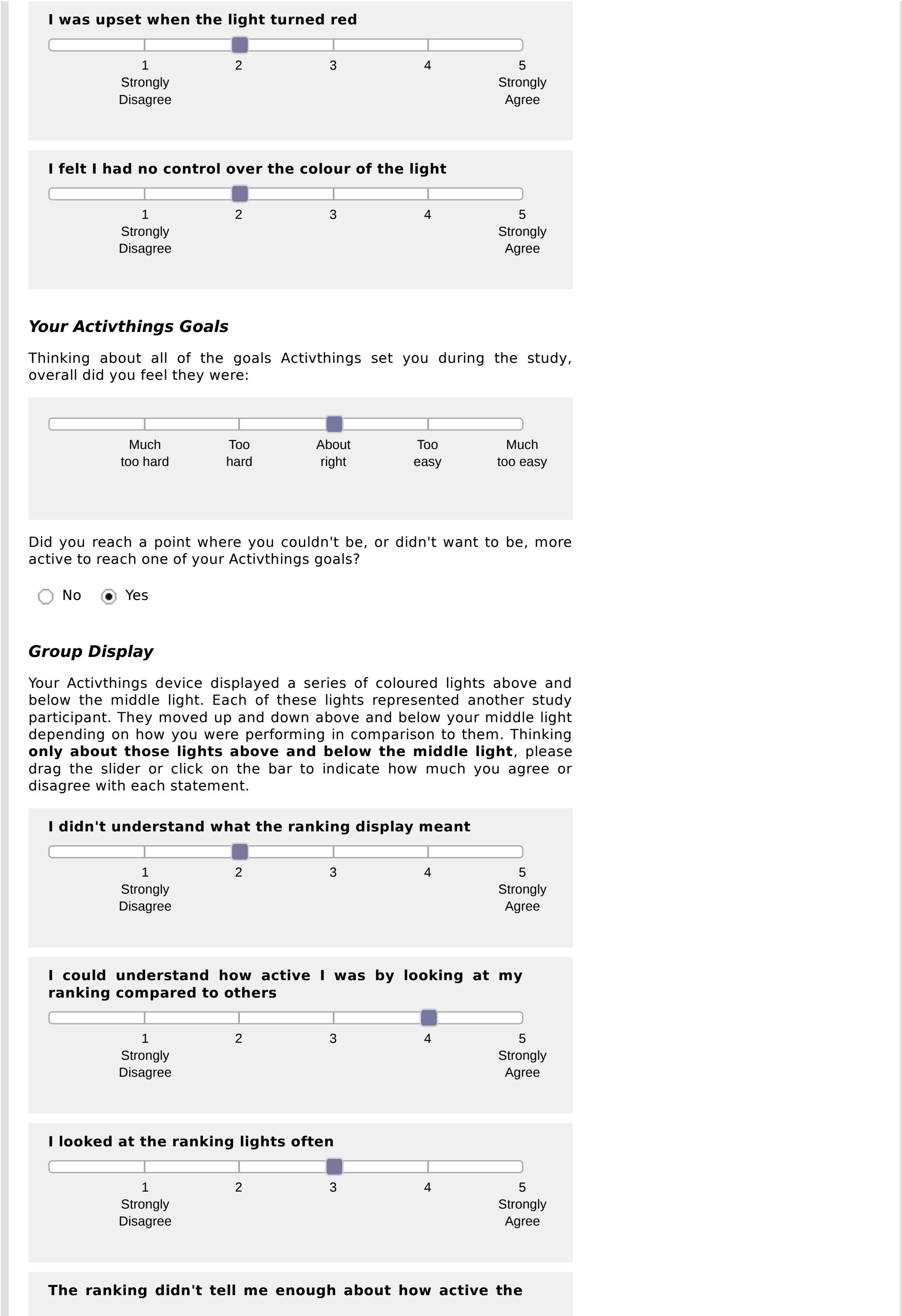
1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree

The light was fun

1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree

I was happy when the light turned green

1 Strongly Disagree — 2 — 3 — 4 — 5 Strongly Agree



I was upset when the light turned red

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I felt I had no control over the colour of the light

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

Your Activthings Goals

Thinking about all of the goals Activthings set you during the study, overall did you feel they were:

Much too hard | Too hard | About right | Too easy | Much too easy

Did you reach a point where you couldn't be, or didn't want to be, more active to reach one of your Activthings goals?

No Yes

Group Display

Your Activthings device displayed a series of coloured lights above and below the middle light. Each of these lights represented another study participant. They moved up and down above and below your middle light depending on how you were performing in comparison to them. Thinking **only about those lights above and below the middle light**, please drag the slider or click on the bar to indicate how much you agree or disagree with each statement.

I didn't understand what the ranking display meant

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I could understand how active I was by looking at my ranking compared to others

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I looked at the ranking lights often

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

The ranking didn't tell me enough about how active the

other people were

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I felt my ranking against others was unfair

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I noticed the lights change position

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I noticed that I moved up in the rankings after doing exercise

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I noticed that I moved down in the rankings when I hadn't exercised for a while

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

It was hard to move up in the rankings by doing exercise

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I dropped in the rankings quickly when I didn't exercise

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

My position in the rankings accurately reflected how active I was

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I wanted to know who the other people were

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

The ranking system didn't motivate me

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

The ranking system was fun

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I was happy when I moved to the top of the rankings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I was upset when I moved to the bottom of the rankings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I felt I had control over my position in the rankings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

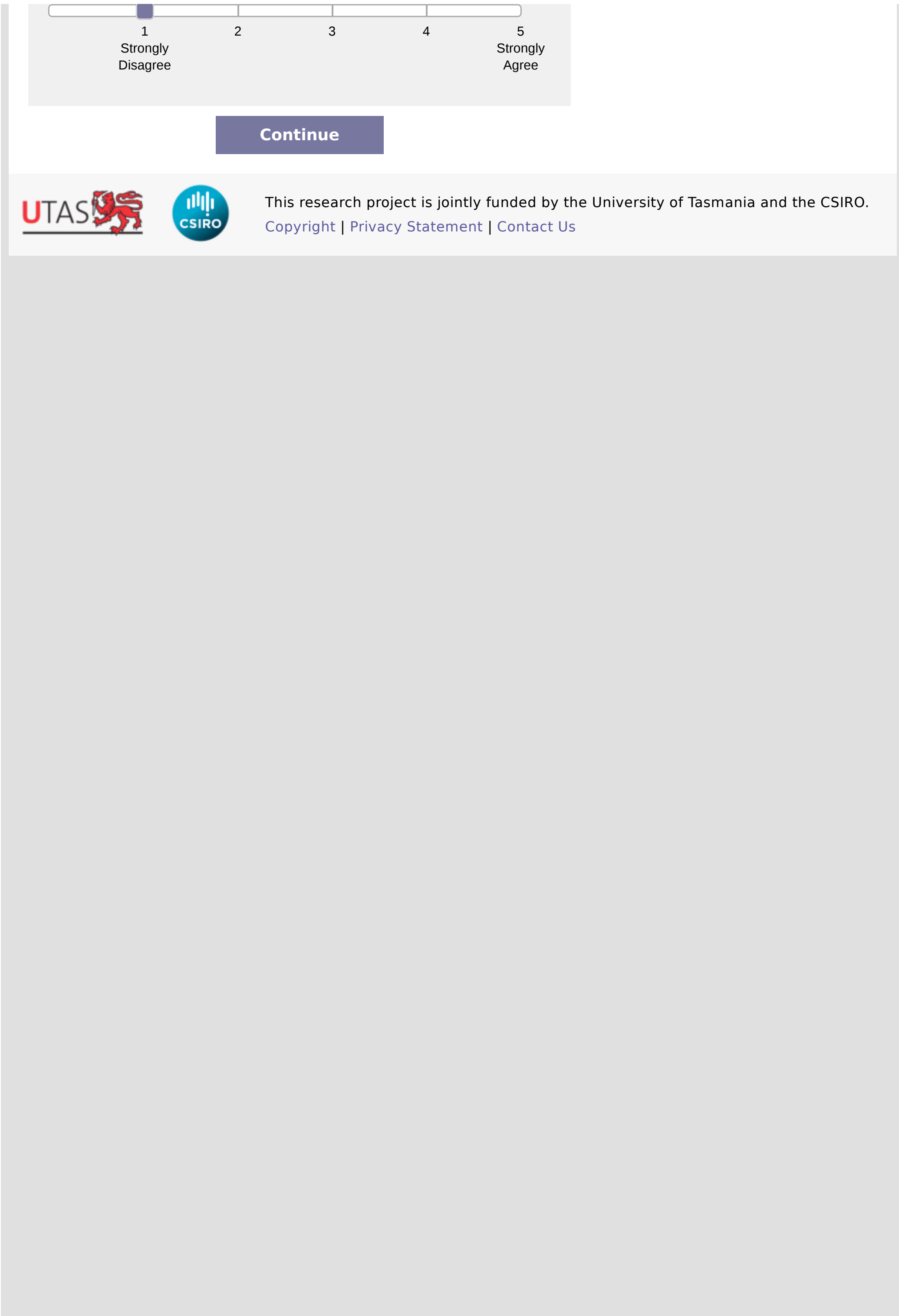
There were too many people in the rankings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I was happy when I saw someone else reach the top of the rankings

1 Strongly Disagree | 2 | 3 | 4 | 5 Strongly Agree

I was upset when I saw someone else reach the top of the rankings


1
Strongly
Disagree
2
3
4
5
Strongly
Agree
Continue
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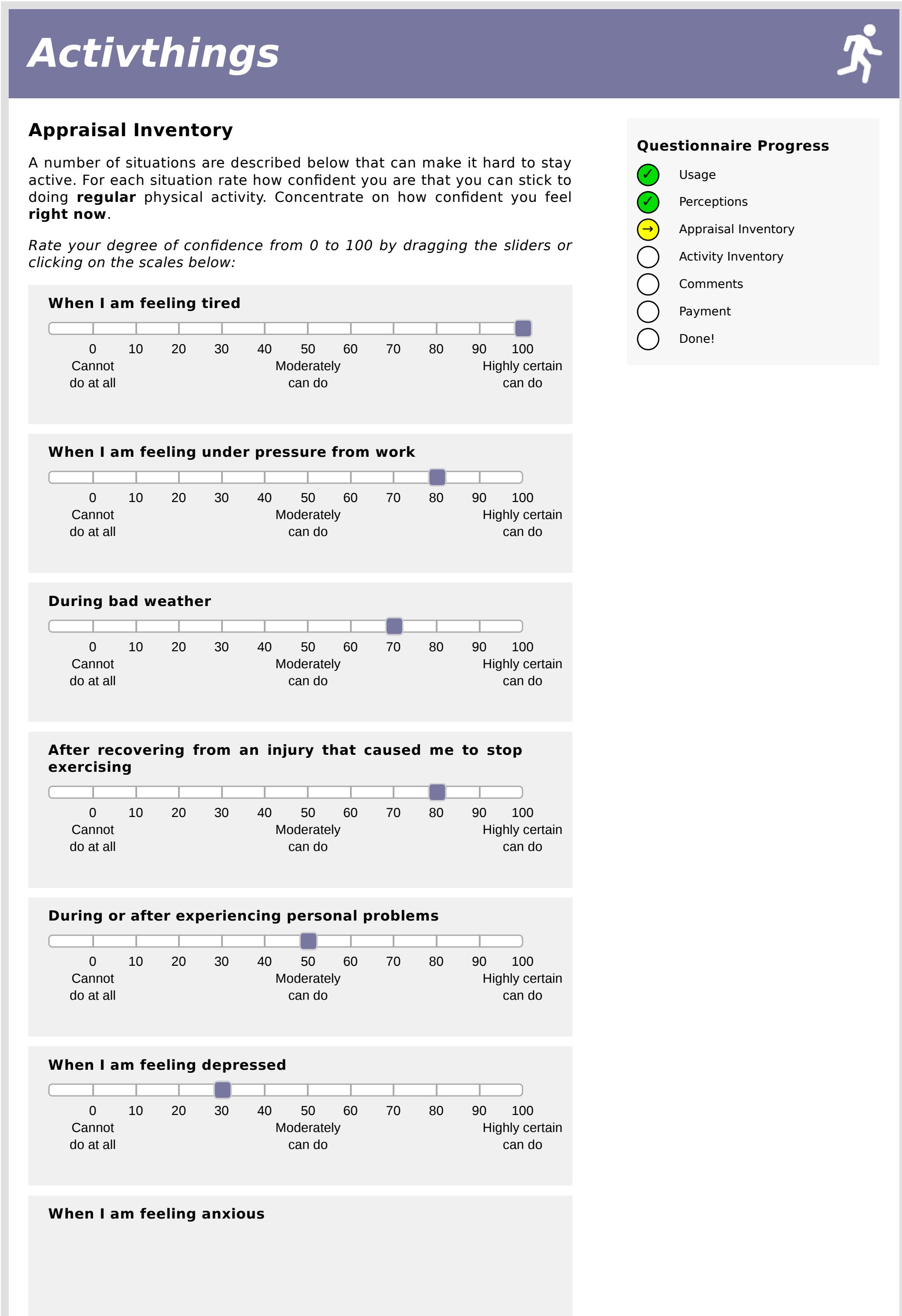

Activthings

Appraisal Inventory

A number of situations are described below that can make it hard to stay active. For each situation rate how confident you are that you can stick to doing **regular** physical activity. Concentrate on how confident you feel **right now**.

Rate your degree of confidence from 0 to 100 by dragging the sliders or clicking on the scales below:

When I am feeling tired

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

When I am feeling under pressure from work

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

During bad weather

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

After recovering from an injury that caused me to stop exercising

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

During or after experiencing personal problems

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

When I am feeling depressed

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all — Moderately can do — Highly certain can do

When I am feeling anxious

Questionnaire Progress

- Usage
- Perceptions
- Appraisal Inventory
- Activity Inventory
- Comments
- Payment
- Done!


0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
After recovering from an illness that caused me to stop exercising
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I feel physical discomfort when I exercise
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
After a holiday
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I have too much work to do at home
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When visitors are present
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When there are other interesting things to do
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
If I don't reach my exercise goals
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
Without support from my family and friends
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do

During a holiday

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all					Moderately can do					Highly certain can do

When I have other time commitments

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all					Moderately can do					Highly certain can do

After experiencing family problems

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all					Moderately can do					Highly certain can do

Continue

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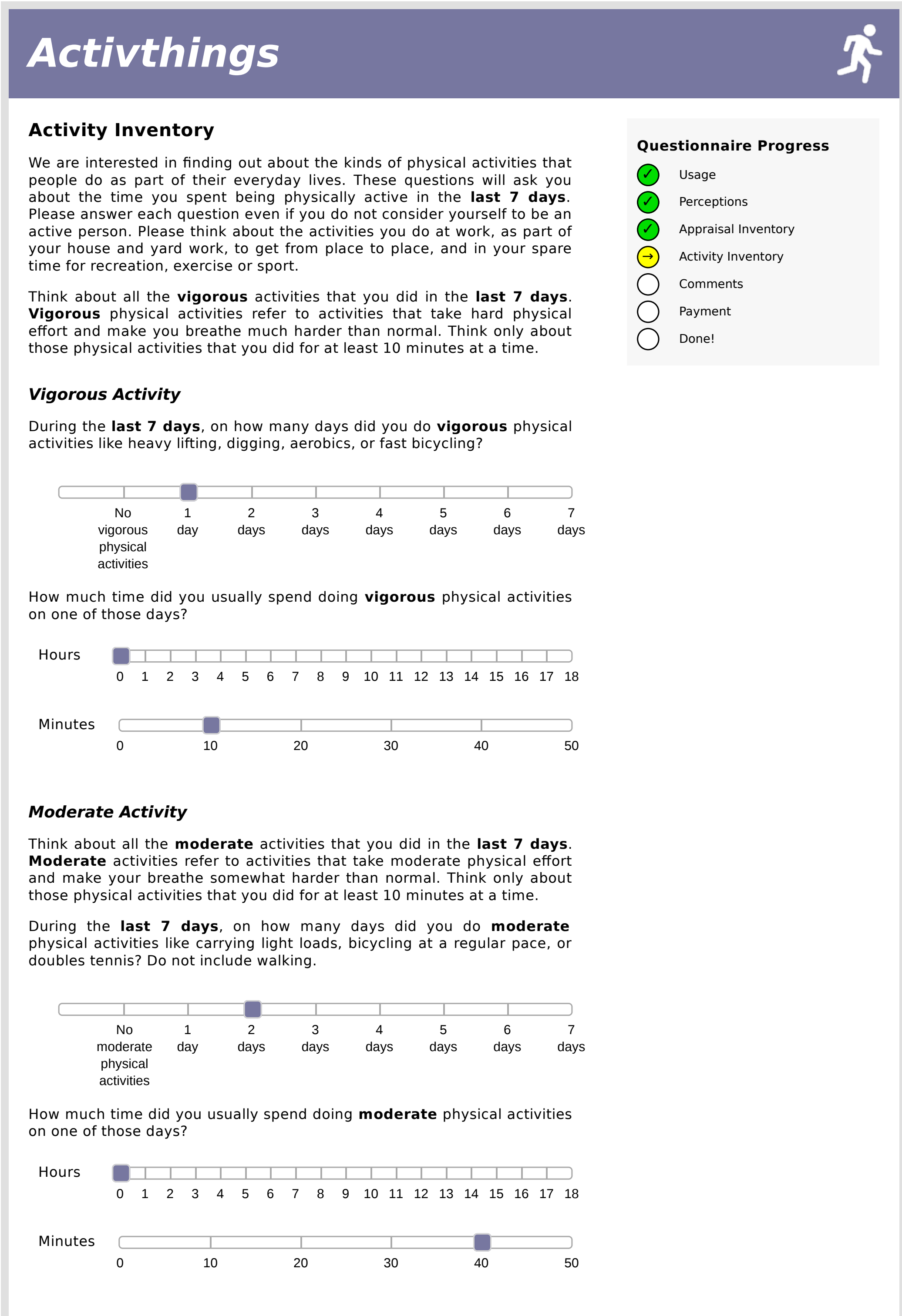


Activthings

Activity Inventory

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. These questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

Vigorous Activity

During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

No vigorous physical activities | 1 day | 2 days | 3 days | 4 days | 5 days | 6 days | 7 days

How much time did you usually spend doing **vigorous** physical activities on one of those days?

Hours: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes: 0 10 20 30 40 50

Moderate Activity

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

No moderate physical activities | 1 day | 2 days | 3 days | 4 days | 5 days | 6 days | 7 days

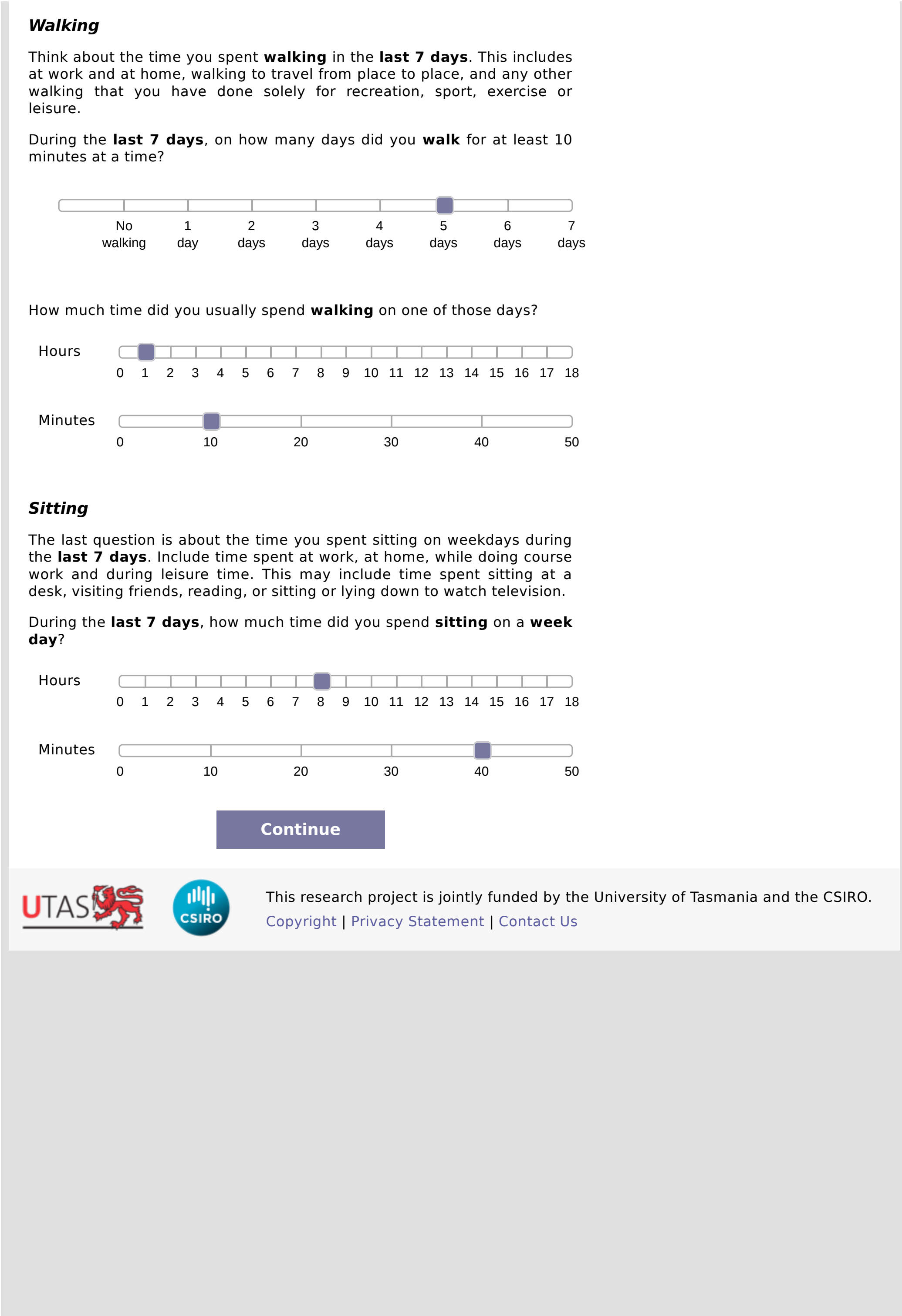
How much time did you usually spend doing **moderate** physical activities on one of those days?

Hours: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes: 0 10 20 30 40 50

Questionnaire Progress

- Usage
- Perceptions
- Appraisal Inventory
- Activity Inventory
- Comments
- Payment
- Done!


Walking
Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise or leisure.
During the last 7 days, on how many days did you walk for at least 10 minutes at a time?
No walking
1 day
2 days
3 days
4 days
5 days
6 days
7 days
How much time did you usually spend walking on one of those days?
Hours
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Minutes
0 10 20 30 40 50
Sitting
The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.
During the last 7 days, how much time did you spend sitting on a week day?
Hours
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Minutes
0 10 20 30 40 50
Continue
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Activthings

Your Comments

Finally, we'd like to give you the opportunity to tell us in your own words some of your thoughts about Activthings and our research study. Please note that entering comments in the text boxes is optional, but we appreciate any feedback you might like to provide.

The Activthings device you've been using is a prototype. Imagine an Activthings device with the same sensor and lights but improved so that it could be sold in stores.

Firstly, what form would it take? A bracelet, like it is now, or something else?

- ○ I wouldn't want one regardless of appearance
- ◉ A wristband/bracelet (like now)
- ○ A digital watch
- ○ An analogue watch
- ○ A necklace
- ○ A shoe or something that attaches to a shoe
- ○ An item of clothing
- ○ Something else

How would this "improved" Activthings device be different from the current one? How would it be similar?

We'd like to know how much you'd pay for this “improved” Activthings device. Obviously we all like a great deal, but we'd like you to think about the **maximum** amount of money you'd be prepared to pay.

Nothing | $25 | $50 | $75 | $100 | $125 | $150 | More than $150

Why would you pay/not pay this much?

How did you hear about our research study?

Questionnaire Progress

- ✓ Usage
- ✓ Perceptions
- ✓ Appraisal Inventory
- ✓ Activity Inventory
- → Comments
- ○ Payment
- ○ Done!

What attracted you to sign up to our research study?

What were you hoping to get out of your participation in the study?

Did you get what you were looking for?

What did you like most about the Activthings device, wearing the device and the study?

What did you like least about the Activthings device, wearing the device and the study?

Are there any other things you would like to say to us about the Activthings device, about your time wearing it or about our research study that we haven't covered yet? Please feel free to be frank – your answers will be anonymous.

Continue

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Activthings

Participation Payment

To thank you for your time, and to cover any out-of-pocket expenses you may have incurred, we're happy to offer you a small participation payment. This will be up to $20 depending on how long you used the Activthings device. If you incur postage costs returning Activthings to us, we will re-imburse you for postage in addition to your participation payment.

All payments will be made by PayPal. If you already have a PayPal account, enter the email address associated with your account below. If you don't have a PayPal account, enter your preferred email address and you will be sent instructions to create one. Once you have received the funds in your PayPal account you may withdraw them to your bank account or use them for online purchases.

Payment email:

participant@example.com

If you do not wish to receive any payment, simply leave the box blank.

iPad Draw

We'd like to ask you some more questions in another six weeks' time, to see how you've been doing following the study. If you complete these final questions you'll be entered into a draw to win an iPad (any model to a value of $598). If for some reason you don't want to be contacted further, please un-check the box below

- [x] Please email me in six weeks with follow-up questions so that I can be entered into the iPad draw.

Continue

Questionnaire Progress

- ✓ Usage
- ✓ Perceptions
- ✓ Appraisal Inventory
- ✓ Activity Inventory
- ✓ Comments
- → Payment
- Done!

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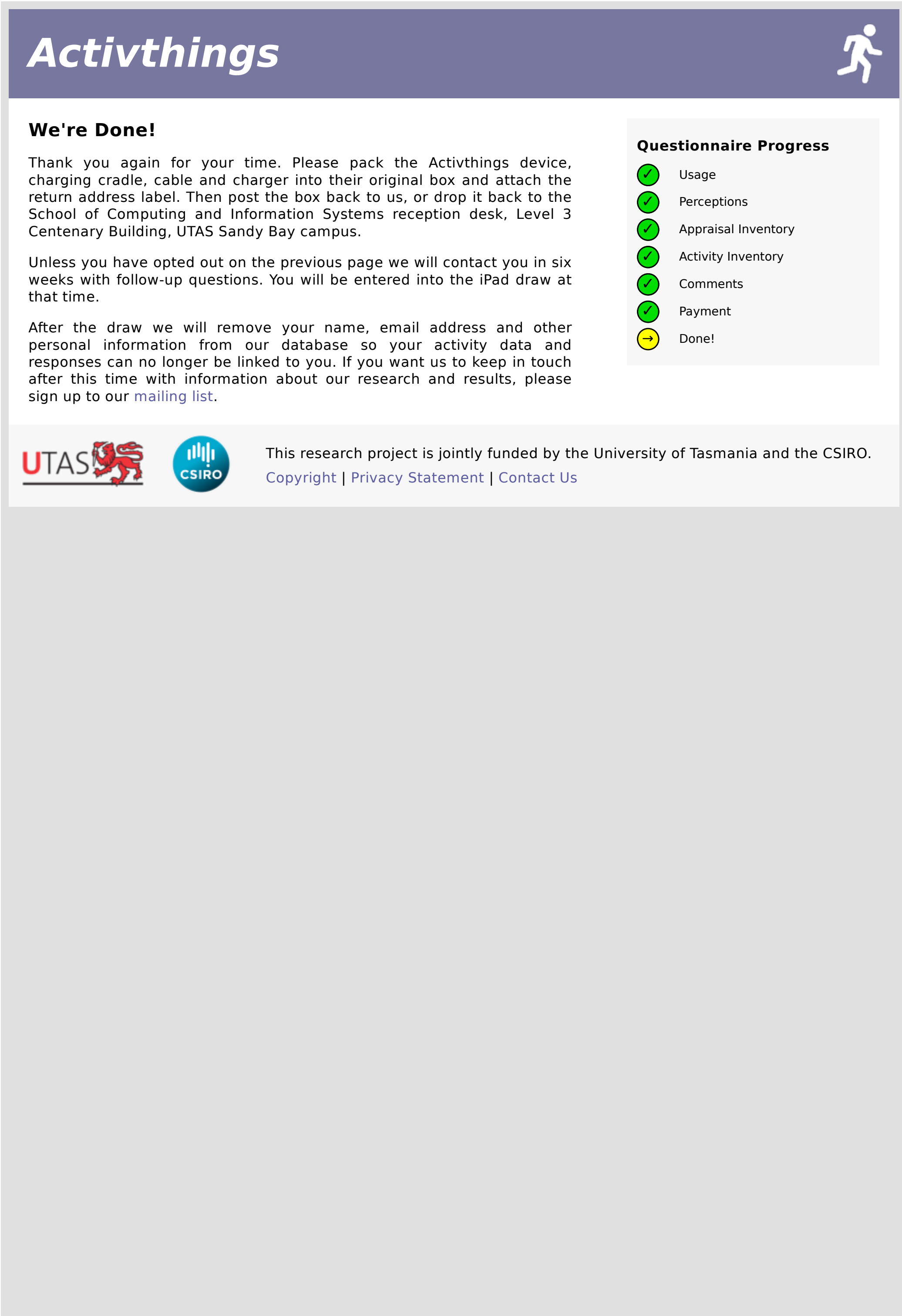

Activthings

We're Done!

Thank you again for your time. Please pack the Activthings device, charging cradle, cable and charger into their original box and attach the return address label. Then post the box back to us, or drop it back to the School of Computing and Information Systems reception desk, Level 3 Centenary Building, UTAS Sandy Bay campus.

Unless you have opted out on the previous page we will contact you in six weeks with follow-up questions. You will be entered into the iPad draw at that time.

After the draw we will remove your name, email address and other personal information from our database so your activity data and responses can no longer be linked to you. If you want us to keep in touch after this time with information about our research and results, please sign up to our mailing list.

Questionnaire Progress

- ✓ Usage
- ✓ Perceptions
- ✓ Appraisal Inventory
- ✓ Activity Inventory
- ✓ Comments
- ✓ Payment
- → Done!

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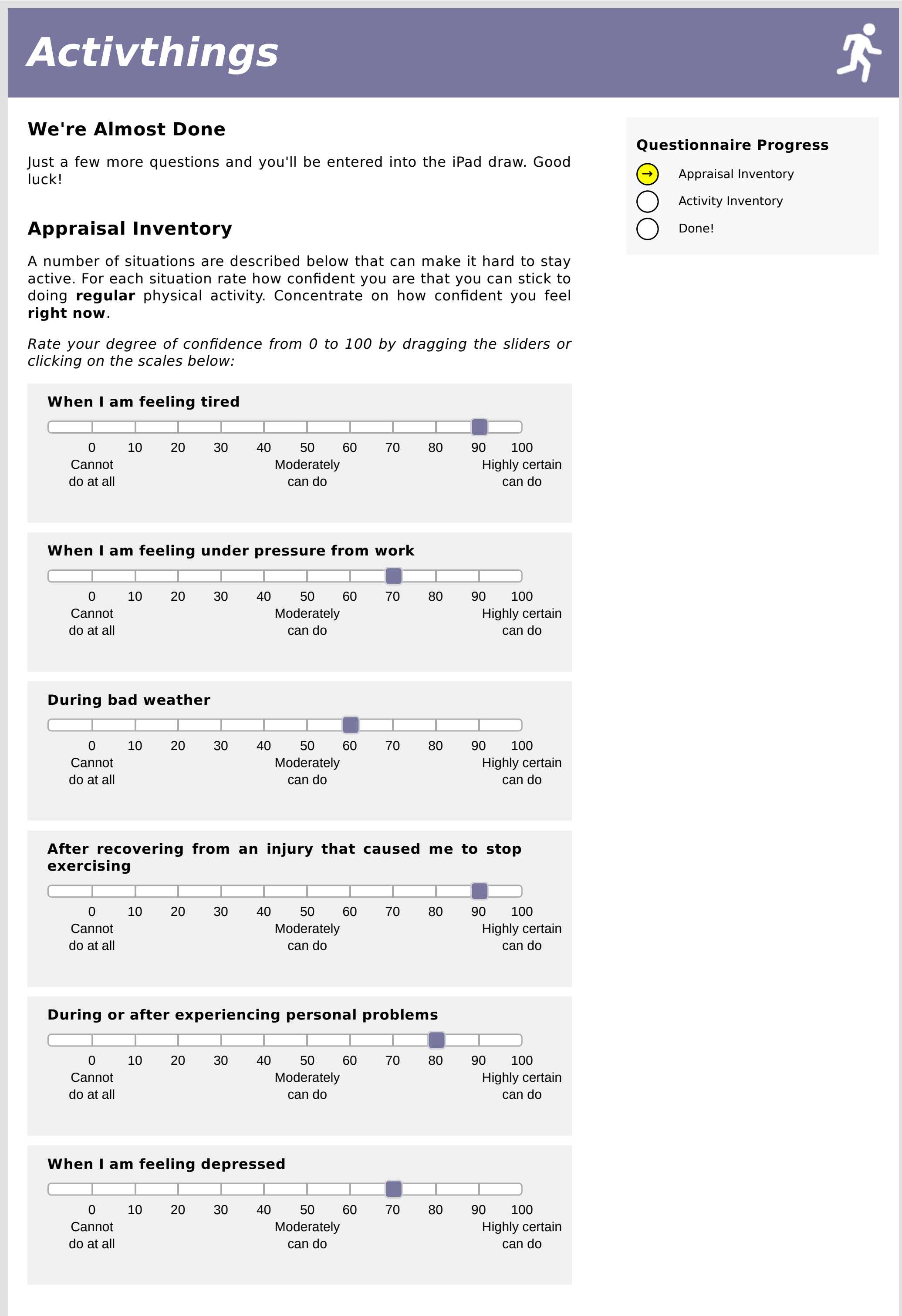
D.2.4 Follow-Up Questions

Participants were asked to complete the following questions three months after the end of the study.



Activthings

We're Almost Done

Just a few more questions and you'll be entered into the iPad draw. Good luck!

Appraisal Inventory

A number of situations are described below that can make it hard to stay active. For each situation rate how confident you are that you can stick to doing **regular** physical activity. Concentrate on how confident you feel **right now**.

Rate your degree of confidence from 0 to 100 by dragging the sliders or clicking on the scales below:

When I am feeling tired

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all / Moderately can do / Highly certain can do

When I am feeling under pressure from work

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all / Moderately can do / Highly certain can do

During bad weather

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all / Moderately can do / Highly certain can do

After recovering from an injury that caused me to stop exercising

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all / Moderately can do / Highly certain can do

During or after experiencing personal problems

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all / Moderately can do / Highly certain can do

When I am feeling depressed

0 10 20 30 40 50 60 70 80 90 100
Cannot do at all / Moderately can do / Highly certain can do

Questionnaire Progress

- Appraisal Inventory
- Activity Inventory
- Done!

When I am feeling anxious

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

After recovering from an illness that caused me to stop exercising

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

When I feel physical discomfort when I exercise

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

After a holiday

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

When I have too much work to do at home

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

When visitors are present

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

When there are other interesting things to do

0 10 20 30 40 50 60 70 80 90 100

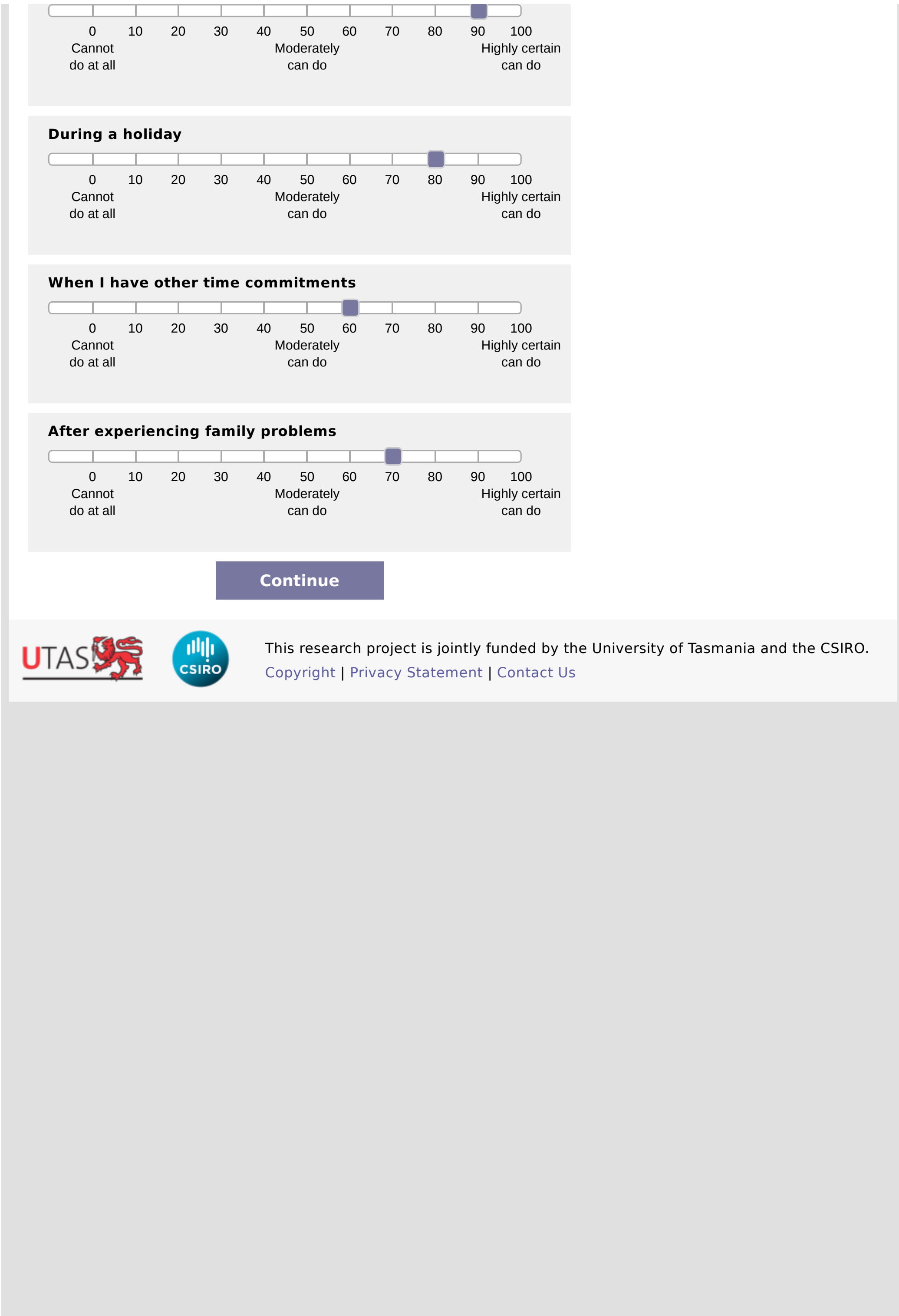
Cannot do at all — Moderately can do — Highly certain can do

If I don't reach my exercise goals

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all — Moderately can do — Highly certain can do

Without support from my family and friends


0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
During a holiday
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
When I have other time commitments
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
After experiencing family problems
0 10 20 30 40 50 60 70 80 90 100
Cannot do at all
Moderately can do
Highly certain can do
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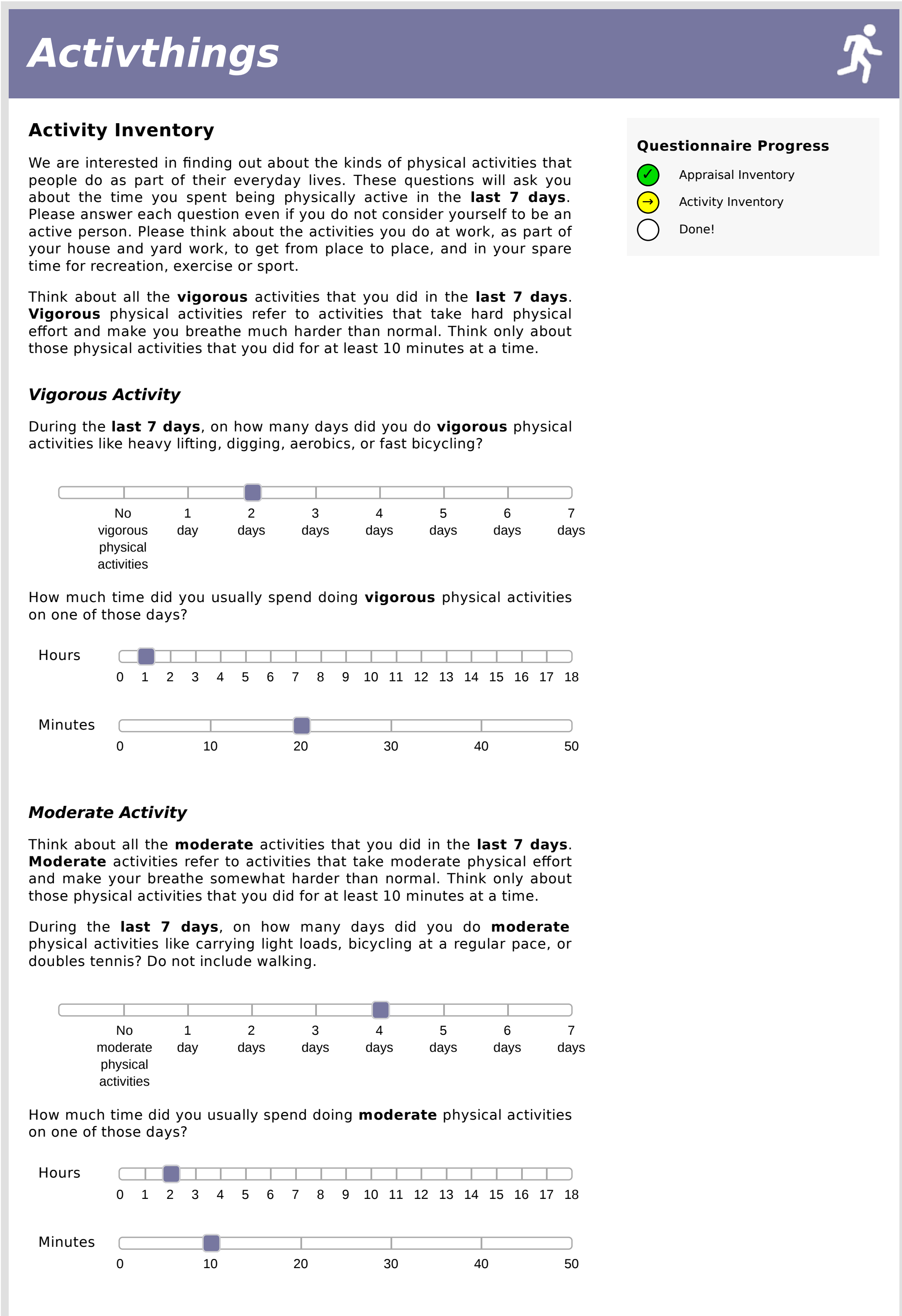
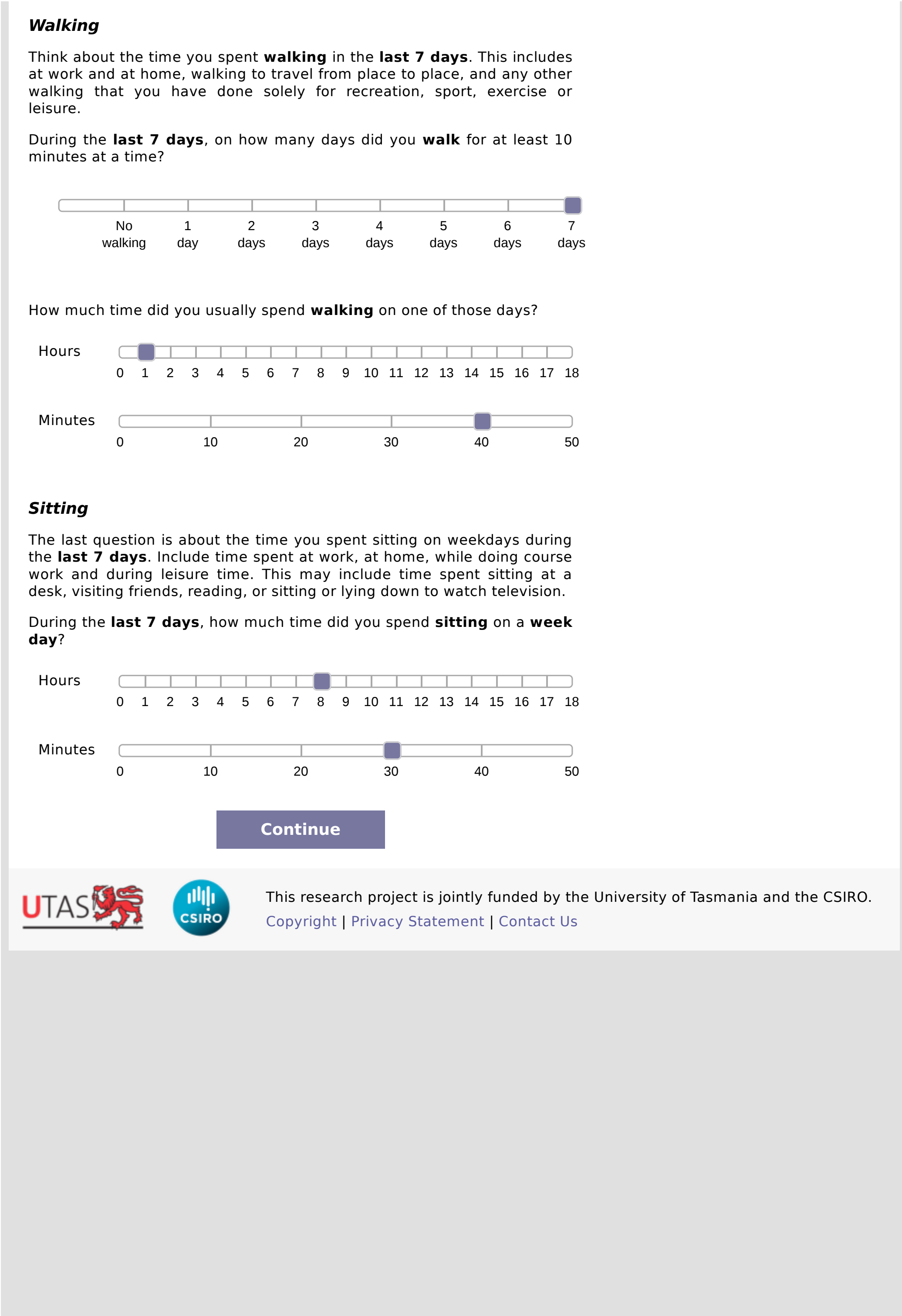

Activthings
Activity Inventory
We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. These questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.
Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.
Vigorous Activity
During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?
No vigorous physical activities
1 day
2 days
3 days
4 days
5 days
6 days
7 days
How much time did you usually spend doing vigorous physical activities on one of those days?
Hours
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Minutes
0 10 20 30 40 50
Moderate Activity
Think about all the moderate activities that you did in the last 7 days. Moderate activities refer to activities that take moderate physical effort and make your breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.
During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.
No moderate physical activities
1 day
2 days
3 days
4 days
5 days
6 days
7 days
How much time did you usually spend doing moderate physical activities on one of those days?
Hours
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Minutes
0 10 20 30 40 50
Questionnaire Progress
Appraisal Inventory
Activity Inventory
Done!



Walking

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise or leisure.

During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

No walking | 1 day | 2 days | 3 days | 4 days | 5 days | 6 days | 7 days

How much time did you usually spend **walking** on one of those days?

Hours 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes 0 10 20 30 40 50

Sitting

The last question is about the time you spent sitting on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

Hours 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Minutes 0 10 20 30 40 50

Continue

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Activthings

We're Done!

Thank you again for your time. We'll be in touch in the next few weeks to let you know the outcome of the iPad draw. Good luck!

After the draw we will remove your name, email address and other personal information from our database so your activity data and responses can no longer be linked to you. If you want us to keep in touch after this time with information about our research and results, please sign up to our mailing list.

Questionnaire Progress

- Appraisal Inventory
- Activity Inventory
- Done!

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Appendix E

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BIBLIOGRAPHY

Ambient Devices. (2014, January). *Consumer Devices.* Retrieved from `http://www.ambientdevices.com/about/consumer-devices`

Andrews, G. (2007). Dance Dance Revolution. *Space Time Play*, 20–21.

Arroyo, E., Bonanni, L., & Selker, T. (2005). Waterbot: Exploring Feedback and Persuasive Techniques at the Sink. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 631–639). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1054972.1055059` doi: 10.1145/1054972.1055059

AtariAge. (2014, January). *Atari 2600 - Controllers - Joyboard.* Retrieved from `http://www.atariage.com/controller_page.html?SystemID=2600&ControllerID=11`

AtariHQ. (2005, January). *AGH Museum - Suncom Aerobics Joystick.* Retrieved from `http://www.atarihq.com/museum/2678/hardware/aerobics.html`

Australian Bureau of Statistics. (2010). *3235.0 - Population by Age and Sex, Regions of Australia, 2010.* Retrieved from `http://www.abs.gov.au/ausstats/abs@.nsf/Products/3235.0~2010~Main+Features~Tasmania`

Australian Bureau of Statistics. (2013, June). *4338.0 - Profiles of Health, Australia, 2011-13.* Retrieved from `http://www.abs.gov.au/`

Baghaei, N., Freyne, J., Kimani, S., Smith, G., Berkovsky, S., Bhandari, D., ... Paris, C. (2009). SOFA: An Online Social Network for Engaging and Motivating Families to Adopt a Healthy Lifestyle. In *Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7* (pp. 269–272). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1738826.1738871` doi: 10.1145/1738826.1738871

Bandura, A. (1991). Social cognitive theory of self-regulation. *Organizational behavior and human decision processes*, *50*(2), 248–287.

Bandura, A. (2006). Guide for constructing self-efficacy scales. *Self-efficacy beliefs of adolescents*, *5*, 307–337.

Basis. (2014, January). *Basis - health and heart rate monitor for wellness and fitness.* Retrieved from `http://www.mybasis.com/basis-healthy-habits-technology/`

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), 1–48. doi: 10.18637/jss.v067.i01

Berkovsky, S., Freyne, J., & Coombe, M. (2012, December). Physical Activity Motivating Games: Be Active and Get Your Own Reward. *ACM Trans. Comput.-Hum. Interact.*, *19*(4), 32:1–32:41. Retrieved from `http://doi.acm.org/10.1145/2395131.2395139` doi: 10.1145/2395131.2395139

BodyMedia. (2014, January). *BodyMedia - Reach Your Health & Fitness Goals with BodyMedia FIT.* Retrieved from `http://www.bodymedia.com/`

Boing Boing. (2008, May). *From Atari Joyboard to Wii Fit: 25 years of "exergaming".* Retrieved from `http://gadgets.boingboing.net/2008/05/15/from-atari-joyboard.html`

Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, *195*(9131/03), 3508–1381.

Bouten, C., Koekkoek, K., Verduin, M., Kodde, R., & Janssen, J. (1997, March). A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity. *Biomedical Engineering, IEEE Transactions on*, *44*(3), 136-147. doi: 10.1109/10.554760

Burns, P., Lueg, C., & Berkovsky, S. (2011). ActivMON: A Wearable Ambient Activity Display. In *MMS 2011: Mobile and ubiquitare Informationssysteme* (Vol. 185, pp. 11–24).

Burns, P., Lueg, C., & Berkovsky, S. (2012a). Activmon: Encouraging Physical Activity Through Ambient Social Awareness. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (pp. 2363–2368). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/2212776.2223803` doi: 10.1145/2212776.2223803

Burns, P., Lueg, C., & Berkovsky, S. (2012b). Empower Everybody-Designing Persuasive Wearable Technology for User Empowerment. In *2nd International Workshop: The Body in Design (part of OzCHI12)* (Vol. 1, pp. 4–7).

Burns, P., Lueg, C., & Berkovsky, S. (2012c). Using Personal Informatics to Motivate Physical Activity: Could we be doing it wrong? In *CHI 2012 Workshop* (Vol. 1, p. EJ).

Burns, P., Lueg, C., & Berkovsky, S. (2013). Colours That Move You: Persuasive Ambient Activity Displays. In *Proceedings of the 8th International Conference on Persuasive Technology* (pp. 27–32). Berlin, Heidelberg: Springer-Verlag. Retrieved from `http://dx.doi.org/10.1007/978-3-642-37157-8_5` doi: 10.1007/978-3-642-37157-8_5

Campbell, T., Ngo, B., & Fogarty, J. (2008). Game Design Principles in Everyday Fitness Applications. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (pp. 249–252). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1460563.1460603` doi: 10.1145/1460563.1460603

Cheok, A. D., Goh, K. H., Liu, W., Farbiz, F., Fong, S. W., Teo, S. L., ... Yang, X. (2004, May). Human Pacman: A Mobile, Wide-area Entertainment System Based on Physical, Social, and Ubiquitous Computing. *Personal Ubiquitous Comput.*, *8*(2), 71–81. Retrieved from `http://dx.doi.org/10.1007/s00779-004-0267-x` doi: 10.1007/s00779-004-0267-x

Chuah, M., & Sample, S. (2011). Fitness Tour: A Mobile Application for Combating Obesity. In *Proceedings of the First ACM MobiHoc Workshop on Pervasive Wireless Healthcare* (pp. 9:1–9:5). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/2007036.2007048` doi: 10.1145/2007036.2007048

Colagiuri, S., Lee, C. M., Colagiuri, R., Magliano, D., Shaw, J. E., Zimmet, P. Z., ... others (2010). The cost of overweight and obesity in Australia. *Med J Aust*, *192*(5), 260–4.

Consolvo, S., Everitt, K., Smith, I., & Landay, J. A. (2006). Design Requirements for Technologies That Encourage Physical Activity. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 457–466). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1124772.1124840` doi: 10.1145/1124772.1124840

Consolvo, S., Klasnja, P., McDonald, D. W., Avrahami, D., Froehlich, J., LeGrand, L., ... Landay, J. A. (2008). Flowers or a Robot Army?: Encouraging Awareness & Activity with Personal, Mobile Displays. In *Proceedings of the 10th International Conference on Ubiquitous Computing* (pp. 54–63). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1409635.1409644` doi: 10.1145/1409635.1409644

Consolvo, S., McDonald, D. W., & Landay, J. A. (2009). Theory-driven Design Strategies for Technologies That Support Behavior Change in Everyday Life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 405–414). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1518701.1518766` doi: 10.1145/1518701.1518766

Department of Health. (2005, November). *An active way to better health: national physical activity guidelines for adults.* Retrieved from `http://www.health.gov.au/internet/main/publishing.nsf/Content/phd-physical-activity-adults-pdf-cnt.htm`

Dey, A. K., Wac, K., Ferreira, D., Tassini, K., Hong, J.-H., & Ramos, J. (2011). Getting Closer: An Empirical Investigation of the Proximity of User to Their Smart Phones. In *Proceedings of the 13th International Conference on Ubiquitous Computing* (pp. 163–172). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/2030112.2030135` doi: 10.1145/2030112.2030135

Everett, B., Salamonson, Y., & Davidson, P. M. (2009). Bandura's exercise self-efficacy scale: Validation in an Australian cardiac rehabilitation setting. *International Journal of Nursing Studies*, *46*(6), 824–829.

Fitbit. (2014a, January). *Fitbit Flex Wireless Activity & Sleep Wristband.* Retrieved from `http://www.fitbit.com/au/flex`

Fitbit. (2014b, January). *Fitbit One Wireless Activity & Sleep Tracker.* Retrieved from `http://www.fitbit.com/au/one`

Fogg, B. (2003). *Persuasive Technology: Using Computers to Change what We Think and Do.* Morgan Kaufmann.

Fogg, B. (2009). A behavior model for persuasive design. In *Proceedings of the 4th international Conference on Persuasive Technology* (p. 40).

Freyne, J., Bhandari, D., Berkovsky, S., Borlyse, L., Campbell, C., & Chau, S. (2010). Mobile Mentor: Weight Management Platform. In *Proceedings of the 15th International Conference on Intelligent User Interfaces* (pp. 409–410). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1719970.1720046` doi: 10.1145/1719970.1720046

Fujiki, Y. (2010). iPhone As a Physical Activity Measurement Platform. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems* (pp. 4315–4320). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1753846.1754146` doi: 10.1145/1753846.1754146

Fujiki, Y., Kazakos, K., Puri, C., Buddharaju, P., Pavlidis, I., & Levine, J. (2008, July). NEAT-o-Games: Blending Physical Activity and Fun in the Daily Routine. *Comput. Entertain.*, *6*(2), 21:1–21:22. Retrieved from `http://doi.acm.org/10.1145/1371216.1371224` doi: 10.1145/1371216.1371224

Fujiki, Y., Tsiamyrtzis, P., & Pavlidis, I. (2009). Making Sense of Accelerometer Measurements in Pervasive Physical Activity Applications. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (pp. 3425–3430). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1520340.1520497` doi: 10.1145/1520340.1520497

Garmin. (2014, January). *Foot Pod.* Retrieved from `https://buy.garmin.com/en-AU/AU/prod15516.html`

Google. (2013, December). *Australian Smartphone Penetration - Think Insights - Google.*

Guo, F., Li, Y., Kankanhalli, M. S., & Brown, M. S. (2013). An Evaluation of Wearable Activity Monitoring Devices. In *Proceedings of the 1st ACM International Workshop on Personal Data Meets Distributed Multimedia* (pp. 31–34). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/2509352.2512882` doi: 10.1145/2509352.2512882

Harrison, C., Lim, B. Y., Shick, A., & Hudson, S. E. (2009). Where to Locate Wearable Displays?: Reaction Time Performance of Visual Alerts from Tip to Toe. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 941–944). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/1518701.1518845 doi: 10.1145/1518701.1518845

Hurling, R., Catt, M., Boni, M. D., Fairley, B. W., Hurst, T., Murray, P., ... others (2007). Using internet and mobile phone technology to deliver an automated physical activity program: randomized controlled trial. *J Med Internet Res*, *9*(2), e7.

IPAQ Group. (2005, November). *Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ) - Short and Long Forms.* Retrieved from https://sites.google.com/site/theipaq/scoring-protocol

Kamal, N., Fels, S., & Ho, K. (2010). Online Social Networks for Personal Informatics to Promote Positive Health Behavior. In *Proceedings of Second ACM SIGMM Workshop on Social Media* (pp. 47–52). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/1878151.1878167 doi: 10.1145/1878151.1878167

Kaye, J. J. (2004, January). Making Scents: Aromatic Output for HCI. *interactions*, *11*(1), 48–61. Retrieved from http://doi.acm.org/10.1145/962342.964333 doi: 10.1145/962342.964333

Kikin-Gil, R. (2005). *BuddyBeads: Mediating social relationship through mobile communications.* Unpublished master's thesis, Interaction Design Institute Ivrea. Retrieved from http://ruthkikin.com/thesis1.html

Klasnja, P., Consolvo, S., & Pratt, W. (2011). How to Evaluate Technologies for Health Behavior Change in HCI Research. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 3063–3072). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/1978942.1979396 doi: 10.1145/1978942.1979396

Kroeze, W., Werkman, A., & Brug, J. (2006). A systematic review of randomized trials on the effectiveness of computer-tailored education on physical activity and dietary behaviors. *Annals of Behavioral Medicine*, *31*(3), 205–223.

Lee, P., Macfarlane, D., Lam, T., & Stewart, S. (2011). Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1). Retrieved from `http://dx.doi.org/10.1186/1479-5868-8-115` doi: 10.1186/1479-5868-8-115

Lee, W., & Lim, Y.-k. (2010). Thermo-message: Exploring the Potential of Heat As a Modality of Peripheral Expression. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems* (pp. 4231–4236). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1753846.1754131` doi: 10.1145/1753846.1754131

Leslie, E., Marshall, A., Owen, N., & Bauman, A. (2005). Engagement and retention of participants in a physical activity website. *Preventive Medicine*, *40*(1), 54 - 59. Retrieved from `http://www.sciencedirect.com/science/article/pii/S0091743504002701` doi: http://dx.doi.org/10.1016/j.ypmed.2004.05.002

Levine, J. A. (2002). Non-exercise activity thermogenesis (NEAT). *Best Practice & Research, Clinical Endocrinology & Metabolism*, *16*(4), 679–702.

Lim, B. Y., Shick, A., Harrison, C., & Hudson, S. E. (2011). Pediluma: Motivating Physical Activity Through Contextual Information and Social Influence. In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 173–180). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1935701.1935736` doi: 10.1145/1935701.1935736

Lin, J. J., Mamykina, L., Lindtner, S., Delajoux, G., & Strub, H. B. (2006). Fish'N'Steps: Encouraging Physical Activity with an Interactive Computer Game. In *Proceedings of the 8th International Conference on Ubiquitous Computing* (pp. 261–278). Berlin, Heidelberg: Springer-Verlag. Retrieved from http://dx.doi.org/10.1007/11853565_16 doi: 10.1007/11853565_16

Lockhart, J. W., & Weiss, G. M. (2014). Limitations with Activity Recognition Methodology & Data Sets. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication* (pp. 747–756). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/2638728.2641306 doi: 10.1145/2638728.2641306

Mackay, M. M. (2013, October). *Australian Mobile Phone Lifestyle Index.* Retrieved from http://www.aimia.com.au/ampli

MacLellan, G., & Baillie, L. (2008). Development of a Location and Movement Monitoring System to Quantify Physical Activity. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems* (pp. 2889–2894). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/1358628.1358779 doi: 10.1145/1358628.1358779

Maitland, J., Sherwood, S., Barkhuus, L., Anderson, I., Hall, M., Brown, B., … Muller, H. (2006). Increasing the awareness of daily activity levels with pervasive computing. In *Pervasive Health Conference and Workshops, 2006* (pp. 1–9).

Mankoff, J., Dey, A. K., Hsieh, G., Kientz, J., Lederer, S., & Ames, M. (2003). Heuristic Evaluation of Ambient Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 169–176). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/642611.642642 doi: 10.1145/642611.642642

Marks, J. T., Campbell, M. K., Ward, D. S., Ribisl, K. M., Wildemuth, B. M., & Symons, M. J. (2006). A comparison of Web and print media for physical activity promotion among adolescent girls. *Journal of Adolescent Health*, *39*(1), 96–104.

Marshall, A. L., Leslie, E. R., Bauman, A. E., Marcus, B. H., & Owen, N. (2003). Print versus website physical activity programs: a randomized trial. *American journal of preventive medicine*, *25*(2), 88–94.

McKay, H. G., King, D., Eakin, E. G., Seeley, J. R., & Glasgow, R. E. (2001). The Diabetes Network Internet-Based Physical Activity Intervention A randomized pilot study. *Diabetes Care*, *24*(8), 1328–1334.

Meyers, B., Brush, A. J. B., Drucker, S., Smith, M. A., & Czerwinski, M. (2006). Dance Your Work Away: Exploring Step User Interfaces. In *CHI '06 Extended Abstracts on Human Factors in Computing Systems* (pp. 387–392). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1125451.1125534` doi: 10.1145/1125451.1125534

Microsoft. (2014, January). *Kinect.* Retrieved from `http://www.xbox.com/en-AU/Kinect`

Miller, T. M., Rich, P., & Davis, J. (2009). ADAPT: Audience Design of Ambient Persuasive Technology. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (pp. 4165–4170). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1520340.1520634` doi: 10.1145/1520340.1520634

Mokka, S., Väätänen, A., Heinilä, J., & Välkkynen, P. (2003). Fitness computer game with a bodily user interface. In *Proceedings of the second international conference on Entertainment computing* (pp. 1–3).

Moloney, L. (2010). *Escapism - An Interactive Display Emvironment For Palliative Care Residents.* Unpublished master's thesis, University of Limerick.

Mueller, F., Agamanolis, S., & Picard, R. (2003). Exertion Interfaces: Sports over a Distance for Social Bonding and Fun. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 561–568). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/642611.642709 doi: 10.1145/642611.642709

Mueller, F. F., & Agamanolis, S. (2005, July). Sports over a Distance. *Comput. Entertain.*, *3*(3), 4–4. Retrieved from http://doi.acm.org/10.1145/1077246.1077261 doi: 10.1145/1077246.1077261

Nawyn, J., Intille, S. S., & Larson, K. (2006). Embedding Behavior Modification Strategies into a Consumer Electronic Device: A Case Study. In *Proceedings of the 8th International Conference on Ubiquitous Computing* (pp. 297–314). Berlin, Heidelberg: Springer-Verlag. Retrieved from http://dx.doi.org/10.1007/11853565_18 doi: 10.1007/11853565_18

Nenonen, V., Lindblad, A., Häkkinen, V., Laitinen, T., Jouhtio, M., & Hämäläinen, P. (2007). Using Heart Rate to Control an Interactive Game. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 853–856). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/1240624.1240752 doi: 10.1145/1240624.1240752

Newman, M. W., Lauterbach, D., Munson, S. A., Resnick, P., & Morris, M. E. (2011). It's Not That I Don't Have Problems, I'm Just Not Putting Them on Facebook: Challenges and Opportunities in Using Online Social Networks for Health. In *Proceedings of the ACM 2011 Conference on Computer Supported Cooperative Work* (pp. 341–350). New York, NY, USA: ACM. Retrieved from http://doi.acm.org/10.1145/1958824.1958876 doi: 10.1145/1958824.1958876

Nielsen, J. (1994). *Usability Engineering.* Elsevier.

Nike. (2014, January). *Nike+ Fuelband SE. Activity Tracker & Fitness Monitor.* Retrieved from http://www.nike.com/us/en_us/c/nikeplus-fuelband

Nyquist, H. (1924). Certain factors affecting telegraph speed. *American Institute of Electrical Engineers, Transactions of the*, *43*, 412–422.

Obrenović, v. (2011, September). Design-based Research: What We Learn when We Engage in Design of Interactive Systems. *interactions*, *18*(5), 56–59. Retrieved from `http://doi.acm.org/10.1145/2008176.2008189` doi: 10.1145/2008176.2008189

Owens, S. G., Garner, J. C. I., Loftin, J. M., van Blerk, N., & Ermin, K. (2011). Changes in physical activity and fitness after 3 months of home Wii Fit use. *The Journal of Strength & Conditioning Research*, *25*(11), 3191–3197.

Peng, W., Lin, J.-H., & Crouse, J. (2011). Is playing exergames really exercising? A meta-analysis of energy expenditure in active video games. *Cyberpsychology, Behavior, and Social Networking*, *14*(11), 681–688.

Prochaska, J. O., & Velicer, W. F. (1997). The Transtheoretical Model of Health Behavior Change. *American Journal of Health Promotion*, *12*(1), 38-48. Retrieved from `http://dx.doi.org/10.4278/0890-1171-12.1.38` (PMID: 10170434) doi: 10.4278/0890-1171-12.1.38

R Core Team. (2016). R: A Language and Environment for Statistical Computing [Computer software manual]. Vienna, Austria. Retrieved from `https://www.R-project.org/`

Rahmati, A., Qian, A., & Zhong, L. (2007). Understanding Human-battery Interaction on Mobile Phones. In *Proceedings of the 9th International Conference on Human Computer Interaction with Mobile Devices and Services* (pp. 265–272). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1377999.1378017` doi: 10.1145/1377999.1378017

Ranasinghe, N., Cheok, A. D., & Nakatsu, R. (2012). Taste/IP: The Sensation of Taste for Digital Communication. In *Proceedings of the 14th ACM International Conference on Multimodal Interaction* (pp. 409–416). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/2388676.2388768` doi: 10.1145/2388676.2388768

Roesch, S. C., Norman, G. J., Villodas, F., Sallis, J. F., & Patrick, K. (2010). Intervention-mediated effects for adult physical activity: A latent growth curve analysis. *Social Science & Medicine*, *71*(3), 494–501.

Rogers, Y. (2006). Moving on from Weiser's Vision of Calm Computing: Engaging Ubicomp Experiences. In *Proceedings of the 8th International Conference on Ubiquitous Computing* (pp. 404–421). Berlin, Heidelberg: Springer-Verlag. Retrieved from `http://dx.doi.org/10.1007/11853565_24` doi: 10.1007/11853565_24

Rogers, Y., Hazlewood, W. R., Marshall, P., Dalton, N., & Hertrich, S. (2010). Ambient Influence: Can Twinkly Lights Lure and Abstract Representations Trigger Behavioral Change? In *Proceedings of the 12th ACM International Conference on Ubiquitous Computing* (pp. 261–270). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1864349.1864372` doi: 10.1145/1864349.1864372

Rowlands, A. V. (2009). *Kinanthropometry and Exercise Physiology Laboratory Manual* (3rd ed., Vol. 1; R. Estron & T. Reilly, Eds.). Taylor & Francis.

Ryan, R. M., Frederick, C. M., Lepes, D., Rubio, N., & Sheldon, K. M. (1997). Intrinsic motivation and exercise adherence. *International Journal of Sport Psychology*, *28*(4), 335-354.

Rydell, S. A., French, S. A., Fulkerson, J. A., Neumark-Sztainer, D., Gerlach, A. F., Story, M., & Christopherson, K. K. (2005). Use of a Web-based component of a nutrition and physical activity behavioral intervention with Girl Scouts. *Journal of the American Dietetic Association*, *105*(9), 1447–1450.

Sacks, G., Rayner, M., & Swinburn, B. (2009). Impact of front-of-pack 'traffic-light' nutrition labelling on consumer food purchases in the UK. *Health promotion international*, *24*(4), 344–352.

Saket, B., Prasojo, C., Huang, Y., & Zhao, S. (2013). Designing an Effective Vibration-based Notification Interface for Mobile Phones. In *Proceedings of the 2013 Conference on Computer Supported Cooperative Work* (pp. 149–1504). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/2441776.2441946` doi: 10.1145/2441776.2441946

Samsung. (2014, January). *Samsung GALAXY Note3+Gear - Design your life.* Retrieved from `http://www.samsung.com/global/microsite/galaxynote3-gear/`

Singh, V., & Mathew, A. P. (2007). WalkMSU: An Intervention to Motivate Physical Activity in University Students. In *CHI '07 Extended Abstracts on Human Factors in Computing Systems* (pp. 2657–2662). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1240866.1241058` doi: 10.1145/1240866.1241058

Sony Computer Entertainment America. (2013, November). *PlayStation Move Motion Controller.* Retrieved from `http://us.playstation.com/ps3/playstation-move/`

Spittaels, H., De Bourdeaudhuij, I., & Vandelanotte, C. (2007). Evaluation of a website-delivered computer-tailored intervention for increasing physical activity in the general population. *Preventive medicine*, *44*(3), 209–217.

Tacx. (2014, January). *tacx.com - Products.* Retrieved from `http://www.tacx.com/`

Thomas, E. S. (2013, December). *The History and Future of Nintendo Portable Gaming.* Retrieved from `http://digthatbox.com/history_and_future_of_nintendo_portable_gaming.html`

Toscos, T., Faber, A., An, S., & Gandhi, M. P. (2006). Chick Clique: Persuasive Technology to Motivate Teenage Girls to Exercise. In *CHI '06 Extended Abstracts on Human Factors in Computing Systems* (pp. 1873–1878). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1125451.1125805` doi: 10.1145/1125451.1125805

Tsai, C. C., Lee, G., Raab, F., Norman, G. J., Sohn, T., Griswold, W. G., & Patrick, K. (2007, March). Usability and Feasibility of PmEB: A Mobile Phone Application for Monitoring Real Time Caloric Balance. *Mob. Netw. Appl.*, *12*(2-3), 173–184. Retrieved from `http://dx.doi.org/10.1007/s11036-007-0014-4` doi: 10.1007/s11036-007-0014-4

Van den Berg, M., Ronday, H., Peeters, A., Le Cessie, S., Van Der Giesen, F., Breedveld, F., & Vliet Vlieland, T. (2006). Using internet technology to deliver a home-based physical activity intervention for patients with rheumatoid arthritis: A randomized controlled trial. *Arthritis Care & Research*, *55*(6), 935–945.

Van den Berg, M. H., Schoones, J. W., & Vlieland, T. P. V. (2007). Internet-based physical activity interventions: a systematic review of the literature. *Journal of Medical Internet Research*, *9*(3).

Volkswagen. (2009, September). *Piano Staircase - The Fun Theory.* Retrieved from `http://www.thefuntheory.com/piano-staircase`

Weiser, M. (1991). The computer for the 21st century. *Scientific american*, *265*(3), 94–104.

Weiser, M., & Brown, J. S. (1996, October). *The Coming Age of Calm Technology.* Retrieved from `http://www.ubiq.com/hypertext/weiser/acmfuture2endnote.htm`

Williams, A., Farnham, S., & Counts, S. (2006). Exploring Wearable Ambient Displays for Social Awareness. In *CHI '06 Extended Abstracts on Human Factors in Computing Systems* (pp. 1529–1534). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1125451.1125731` doi: 10.1145/1125451.1125731

Yim, J., & Graham, T. C. N. (2007). Using Games to Increase Exercise Motivation. In *Proceedings of the 2007 Conference on Future Play* (pp. 166–173). New York, NY, USA: ACM. Retrieved from `http://doi.acm.org/10.1145/1328202.1328232` doi: 10.1145/1328202.1328232